Journal
of
The Franklin Institute
Devoted to Science and the Mechanic Arts

Vol. 184 AUGUST, 1917 No. 2

PHYSICS OF THE AIR *

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INTRODUCTION.

THE physical phenomena of the earth's atmosphere are exceedingly numerous and of great importance. Nevertheless, the explanations, even of those well understood, still remain scattered through many books and numerous journals. Perhaps this is because some of the phenomena have never been explained, and others but imperfectly so, but, however that may be, it is obvious that an orderly assemblage of all those facts and theories that together might be called the *Physics of the Air* would be exceedingly helpful to the student of atmospherics. An attempt to serve this useful purpose led to the production of the following chapters.

The author begs to express his indebtedness to Prof. C. F. Marvin, Chief of the United States Weather Bureau, for numerous helpful criticisms, and to Prof. C. F. Talman, Librarian of the United States Weather Bureau, for valuable aid in locating original sources.

* These papers on the Physics of the Air, constituting an official report prepared by William J. Humphreys, Professor of Meteorological Physics in the Weather Bureau, are published by The Franklin Institute in coöperation with the Weather Bureau.

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PART I.

Mechanics and Thermodynamics of the Atmosphere.

CHAPTER I.

OBSERVATIONS.

BEFORE discussing any of the physical laws of the atmosphere it will be instructive briefly to consider the observational data upon which they are based; that is, to enumerate the meteorological phenomena which commonly are measured, and to indicate in each case the type of instrument generally used. No effort will be made to describe apparatus in detail, nor to discuss the minutiæ of every correction. These important matters are fully taken care of by observers' instructions issued by the United States Weather Bureau and other meteorological services. Besides, they pertain to the technique of the collection of data rather than to the science deduced therefrom, which latter, and not the former, is the object of the present discussion.

MEASURED PHENOMENA.

Temperature.—Probably the most obvious, satisfactory definition of temperature describes it as *that thermal state of an object which enables it to communicate heat to other objects.* Whenever the heat interchange that always takes place between two objects in thermal communication results in a net loss to the one and gain to the other, the temperature of the former is said to have been higher than that of the latter. If, however, there is no net loss or gain by either, the objects are said to have the same temperature.

Detection of net loss or gain may be accomplished in any one of many ways, some of which are: change of volume; change of state; change of electromotive force, and change of electrical resistance. All these, according to circumstances, afford convenient means of comparing the temperatures of different objects, and of establishing a scale for ready reference. Thus the ordinary mercury thermometer, the alcohol thermometer, adapted to low temperatures, and others of this nature, are based on the fact that, corresponding to equal temperature changes, the volume expansion of the vessel is not the same as that of the contained fluid. Such thermometers, though capable of a high

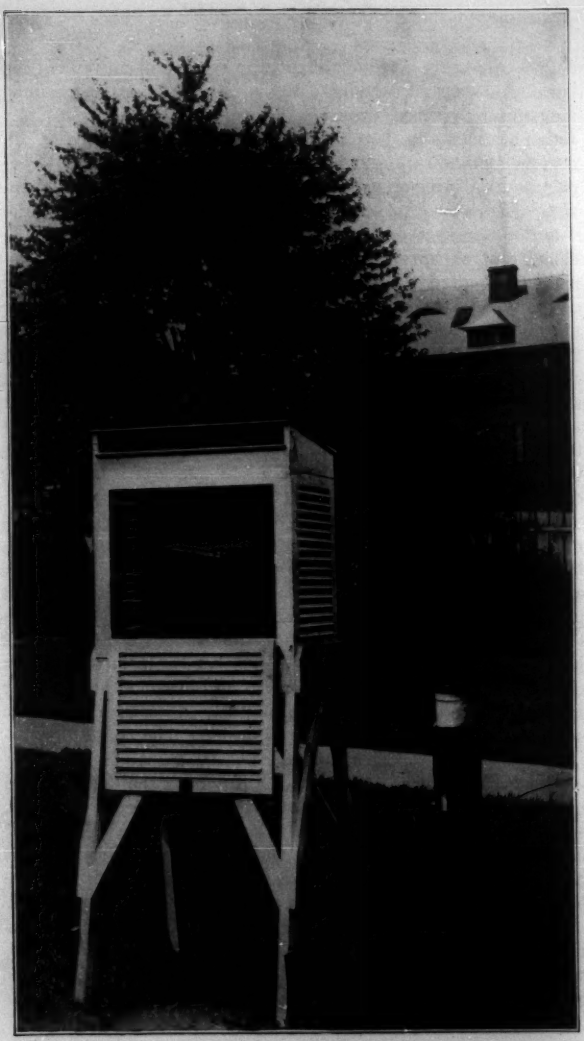


FIG. 1.—Thermometer shelter and rain gauge for coöperative observers.

degree of accuracy, are not adapted to cheap and convenient registration, except of extremes; that is, the maximum or minimum temperature reached since last adjustment. Nevertheless, differential expansion does afford several means of obtaining continuous mechanical registration of temperature. The most compact and satisfactory apparatus of this kind in general use consists essentially of a curved closed tube of oval cross-section —a Bourdon tube—completely filled with a suitable liquid. Inequality of expansion between tube and liquid in this case demands change of volume, and that in turn changes the curvature of the tube. Hence by making one end of the tube fast and connecting the other with a tracing point it at once becomes possible to obtain on a moving surface a complete record of temperature changes. The unequal expansion of the two sides of a bimetallic strip is also utilized in obtaining temperature registration.

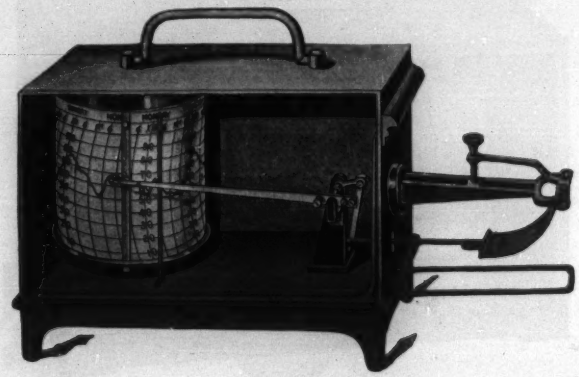
Variation of electrical resistance with change of temperature and the electromotive force at a thermal junction both provide means of measuring temperature changes to a high degree of accuracy.

In the case of the atmosphere, however, temperature commonly is measured at stated intervals, and whenever desired, by the readings of a good mercurial, or, in very cold regions, alcohol, thermometer exposed to full circulation of the air, but protected from both solar and sky radiation. An excellent shelter for this purpose, with maximum and minimum thermometers in place, is shown in Fig. 1. Normally, of course, the door is closed. A less accurate but continuous record of atmospheric temperature usually is secured by the use of either a bimetallic or a Bourdon tube thermograph (Fig. 2). The connection between the thermal element and the tracing point may be either mechanical, as shown, or electrical. In the latter case the two may be separated any desired distance, the first placed outdoors, say, and the second conveniently located in an office. Other methods of measuring and even continuously recording the temperature of the air have been devised, though at present they are but sparingly used, and then, as a rule, only for special purposes.

Pressure.—The pressure of the atmosphere, upon the distribution of which winds and storm movement so vitally depend, ordinarily, is not determined. Measurements, however, equally good for intercomparison, are made to which it is directly pro-

portional, and from which pressures readily might be computed in dynes per square centimetre, or any other specified units. On land the measurement usually taken for this purpose is the height of the barometric column; that is, the difference in level between the two free surfaces of a continuous mass of mercury, one of which is open to the atmosphere, the other *in vacuo*, slightly corrected for temperature effects, capillarity, scale errors, and degree of vacuum. From this corrected height and the local force of gravity the actual air pressure is easily obtained. Further, by reducing the barometric heights simultaneously obtained at different places to what they presumably would be if the sta-

FIG. 2.



Thermograph.

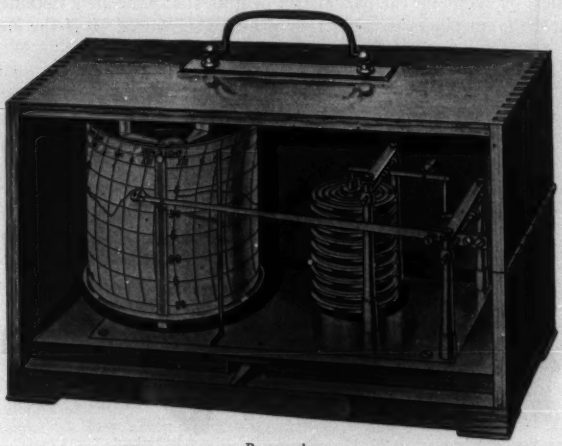
tions all had a certain common level—for which operation appropriate equations are used—data are obtained which, when plotted on a map of the region concerned, show the approximate pressure distribution, from which, in turn, the strength and course of the winds during the next 12 to 24 hours may be closely predicted.

As a rule, the mercurial barometer is read by eye and only as occasion may require, but it also has been so constructed as to give excellent continuous records.

The aneroid, or, as its name implies, non-liquid, barometer, though involving many sources of error, is conveniently portable and capable of fairly satisfactory use in many places—on kites,

aeroplanes, etc.—where the mercurial barometer would be wholly impracticable. It consists essentially of a disk-like vacuum cell, or series of such cells, a few centimetres in diameter, whose corrugated, flexible top and bottom are held apart by a short, stiff spring. Any change in the atmospheric or external pressure obviously must lead to a corresponding flexure of the spring, which motion may be communicated to either an index hand or a recording pen. In the ordinary barograph (Fig. 3) the pen

FIG. 3.



Barograph.

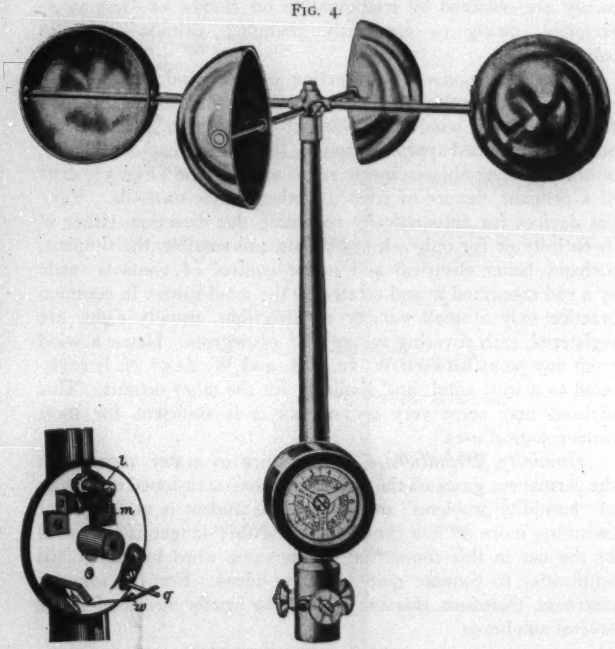
commonly is actuated by a number of aneroid cells placed in series.

Most aneroids, whether single- or multiple-celled, require careful attention and frequent comparison with a standard mercurial instrument. They also are inherently subject to lag errors due to the imperfect elasticity of the cells that vary according to the pressure conditions and the characteristics of the particular instrument, and which, for accurate readings, must always be allowed for.

Wind Velocity.—The velocity of the wind may be determined by triangulation on clouds, balloons, and other floating

objects; by noting the speed of rotation, easily automatically recorded, of a windmill anemometer, air meter, or other similar device, and applying the necessary corrections; by the pressure on a flat surface squarely facing the wind; by the difference in level between the two free surfaces of a liquid in a U-tube

FIG. 4.



Robinson's cup anemometer.

or equivalent vessel when one surface is protected and the other exposed to the full force of the wind; and by a great many other but generally less accurate methods.

The Robinson cup anemometer (Fig. 4) appears to be the most convenient and reliable instrument wherever it can be properly exposed. Rapid velocity changes, manifesting them-

selves in irregular puffs and of great importance to the aviator, the architect, and the engineer, generally are observed and recorded by some quick-acting pressure apparatus, such as the Dines pressure tube anemometer or the Pitot tube.

Wind velocities at considerable heights in the free air commonly are obtained by triangulation on clouds, or—less satisfactorily, owing to constantly changing altitude—on pilot balloons.

Wind Direction.—The direction of the wind, as the term is used in meteorological literature, always means the direction *from* which the wind is blowing at the point in question. It may be determined approximately by the course of smoke, clouds, or other floating objects, by the set of a wind vane (Fig. 5), drift of a pennant, flexure of trees, or other simple methods. Various devices for automatically recording this direction, either in its entirety or for only selected points, are possible, the simplest, perhaps, being electrical and under control of contacts made by a rod connected to and rotated by the wind vane. In common practice only a small number of directions, usually eight, are registered, each covering an angle of 45 degrees. Hence a wind from any point between W. 22.5° S. and W. 22.5° N. is registered as a west wind; and similarly for the other octants. This division may seem very coarse, but it is sufficient for most meteorological uses.

Humidity, Definitions.—The mixture of water vapor with the permanent gases of the atmosphere has occasioned a number of "humidity problems" over which the student is in danger of becoming more or less confused. And this danger is increased by the use in this connection of the same word by recognized authorities to connote quite different ideas. For the sake of clearness, therefore, this subject will be briefly discussed under several sub-heads.

I. *Absolute Humidity.*

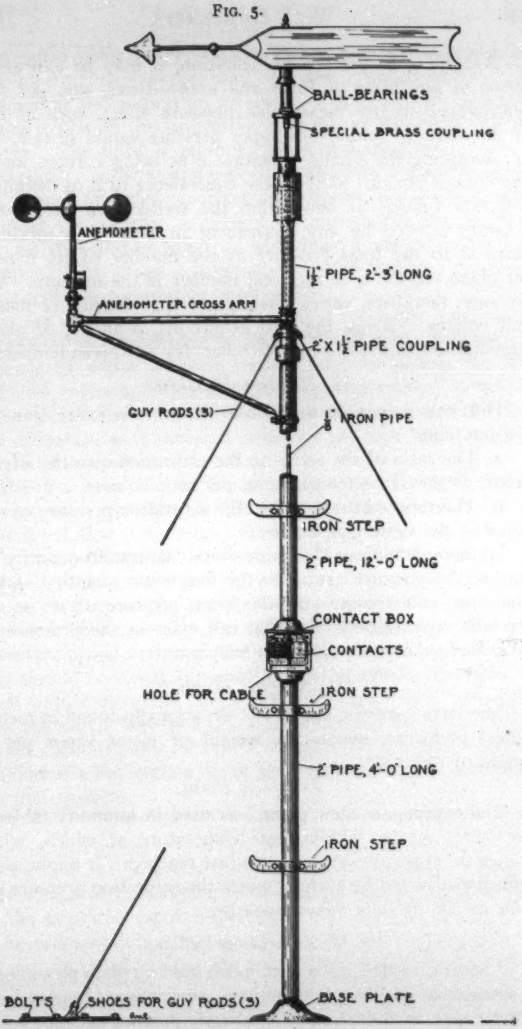
Two entirely different definitions are in use for the common expression "absolute humidity":

a. The mass of water vapor per unit volume.

b. The gas pressure exerted by the water vapor per unit area.

According to the first definition, the absolute humidity may be expressed in terms of any units of mass and volume, as, for instance, grammes per cubic metre.

FIG. 5.



Wind vane and anemometer support, pattern 1913 (showing 4-foot wind vane on ball bearings).

According to the second definition, it may be expressed in terms of any units of force and area—dynes, say, per square centimetre; or any measurable pressure effect, such as height of the mercury column the vapor pressure would sustain.

Accepting the simple definition *a* as being correct, as every one does, it remains to show the equivalence to it of definition *b*. But this follows at once from the well-known fact that the pressure exerted by any constituent in a uniform mixture of gases is to the total pressure as the number of its molecules per given volume is to the total number in the mixture. Vapor pressure, therefore, varies directly as vapor density, or mass per unit volume. Hence the two definitions, *a* and *b*, of absolute humidity are equivalent to each other, for any given temperature.

II. *Relative Humidity.*

Different definitions are also in use for the expression "relative humidity":

a. The ratio of the actual to the saturation quantity of water vapor, at the same temperature, per unit volume.

b. The ratio of the actual to the saturation pressure of water vapor at the same temperature.

In these definitions the expressions "saturation quantity" and "saturation pressure" refer to the maximum quantity of water vapor per unit volume and maximum pressure of water vapor per unit area, respectively, that can exist in the presence of a flat water surface, at the given temperature.

III. *Specific Humidity.*

The term "specific humidity," occasionally found in meteorological literature, means the weight of water vapor per unit weight of moist air.

IV. *Dew Point.*

The expression "dew point," as used in humidity tables and elsewhere, means simply that temperature at which, without change of pressure, saturation is just reached. It might also be defined as that temperature at which the saturation pressure is the same as the existing vapor pressure.

V. *Saturation Deficit.*

"Saturation deficit," a term much used by plant physiologists, is susceptible of several definitions, especially: (1) Amount of water vapor, in addition to that already present, per unit volume,

grammes per cubic metre, say, necessary to produce saturation at the existing temperature and pressure. (2) Difference between actual and saturation pressure. (3) Ratio of the vapor pressure deficit to the saturation pressure at the existing temperature. The third is relative, the others absolute.

Humidity, Instrumentation.—The absolute humidity, in the sense of mass of water vapor per unit volume, can be determined by noting the increase in weight of phosphorus pentoxide or other suitable drying agent on absorbing a known volume of the vapor. This direct determination of the humidity, however, is impracticable for routine observations.

On the other hand, as partial pressure ratios are independent of temperature, the determination of the absolute humidity in the sense of vapor pressure merely requires finding the dew point and referring it to a table of predetermined saturation pressures. Similarly, the difference between the current and dew-point temperatures is sufficient to determine, from suitable tables, the relative humidity.

The dew point may be found by any one of several slightly different methods, all of which have for their basis the determination of that temperature at which moisture just begins to collect on a cooling surface. A thin-walled silver tube, burnished on the outside, is an excellent vessel for the cooling mixture. The temperature of the liquid, if well stirred, and that of such a tube will be very nearly the same, and, besides, the dulling of the surface promptly reveals the slightest condensation.

It should be noted, however, that if carefully taken the observed temperatures of the silver hygrometer will be slightly below the actual "dew point." This is because the initial deposit is in the form of minute droplets, whose vapor pressure is greater than that of a flat surface at the same temperature, in accordance with the equation,[1]

$$\Delta p = \frac{2\,T\rho_v}{R(\rho_w - \rho_v)}$$

in which Δp is the pressure difference, T the surface tension, R the radius of the droplet, ρ_w and ρ_v the densities of the water and the saturated vapor respectively.

At ordinary temperatures and for droplets whose radii are 10^{-4} cm. (a possible size) the temperature depression, or error,

[1] Sir William Thomson, *Proc. Roy. Soc.*, ed. 7, p. 63 (1870).

FIG. 6.—Sling psychrometer.

amounts roughly to 0.02° C. According to the equation, the error obviously might have any value, though actually it seems always to be small, owing to limiting values of R, and presumably also to other causes; that is, this too, like many other physical equations, has its limitations.

In taking humidity measurements the observer must be careful that his presence does not affect the amount of moisture in the air under examination—he must stand to the lee of his apparatus. It is also advisable to average the temperature at which dew just forms when the liquid is slowly cooling and that at which it just disappears when the liquid is slowly warming.

A more expeditious and therefore, for routine observations, a correspondingly more practical method of determining vapor pressure is based on the reliability of the equation,

$$f = f_1 - AB\ (t - t_1)$$

in which t = the air temperature.

t_1 = the evaporation temperature; that is, temperature of a vigorously ventilated wet bulb thermometer.

f = the vapor pressure.

f_1 = saturation pressure at temperature t_1.

B = barometric pressure.

A = a number that, in the case of ample ventilation, varies only with t_1, and with it but slowly.

When f, f_1, and B are expressed in millimetres of mercury under standard conditions and t and t_1 in centigrade values,

$$f = f_1 - 0.000660\ B\ (t - t_1)\ (1 + 0.00115\ t_1).$$

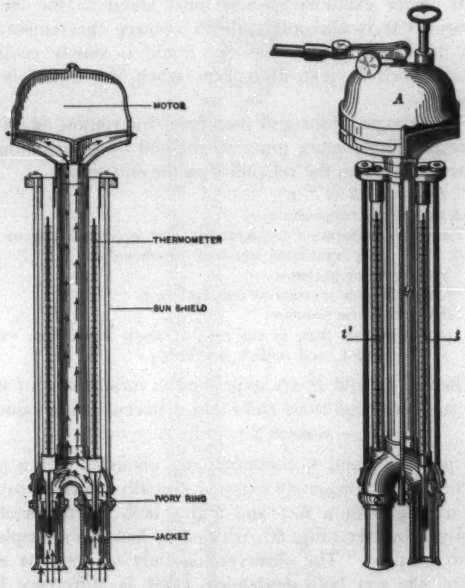
In practice t and t_1 commonly are obtained with a properly constructed and adequately exposed (usually whirled) psychrometer carrying both a wet and a dry bulb thermometer. The sling psychrometer (Fig. 6), whirled by hand, is a simple device for this purpose. The observer has only to note the air temperature, the wet bulb depression (that is, difference between the wet and dry bulb temperatures), and barometric pressure. With these values he reads off from tables the vapor pressure and the dew point.

Assmann's aspiration psychrometer (Fig. 7), however, appears to be the most accurate instrument for this purpose. This consists of two parallel double-walled tubes, silvered to minimize radiation effects, containing a wet and dry bulb thermometer, respectively, united into a common stem and surmounted by a small ventilating fan.

Cloudiness.—The degree of cloudiness generally is expressed in tenths (estimated) of the sky actually overcast.

Kinds of Clouds.—As an indication of the approaching weather and general state of the atmosphere, the kind or kinds of clouds present is more important than the mere total percentage of cloudiness. For convenient reference clouds have

FIG. 7.



Aspiration psychrometer.

been divided into four primary and nine secondary (combination, alto, and fracto) forms.

These are:

PRIMARY FORMS: Cirrus—or curl cloud; stratus—or layer cloud; cumulus—or wool-pack cloud; and nimbus—or rain cloud.

COMBINATION FORMS: Cirro-stratus, cirro-cumulus, strato-cumulus, and cumulo-nimbus.

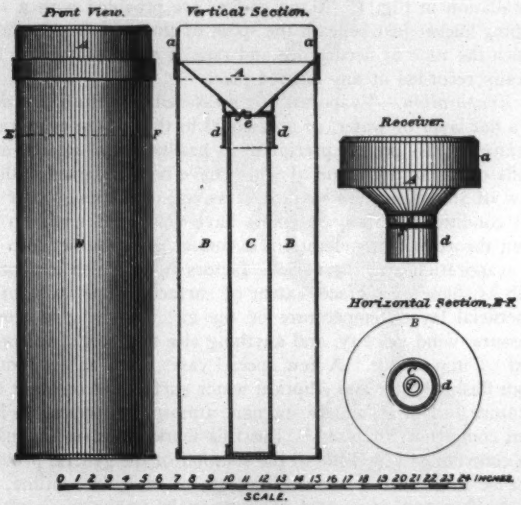
ALTO FORMS: Alto-stratus and alto-cumulus.

FRACTO FORMS: Fracto-stratus, fracto-cumulus, and fracto-nimbus.

The foregoing names are used in the International Cloud Classification, now generally accepted.

It will be noted that several names possible in accordance with this scheme of nomenclature are omitted, even though a few of them have occasionally been used in certain other schemes of classification. Thus there is no cirro-nimbus, for the reason that rain clouds never have the cirrus form; no strato-nimbus, because all rain clouds are flat; no alto-cirrus, because all cirri

FIG. 8.



Rain gauge.

are high; no alto-nimbus, because rain clouds are never high; and no fracto-cirrus, because cirri are always broken and detached.

Most of these clouds may be grouped according to their respective altitudes:

UPPER CLOUDS: Cirrus, cirro-stratus.

INTERMEDIATE CLOUDS: Cirro-cumulus, alto-stratus, alto-cumulus.

LOWER CLOUDS: Strato-cumulus, nimbus, fracto-nimbus, stratus, fracto-stratus.

The cumulus, fracto-cumulus, and cumulo-nimbus, all caused by diurnal convection, vary in altitude from low to intermediate.

Precipitation.—The amount of precipitation is measured in the actual or, in case of snow, equivalent depth of horizontal water layer. The details in respect to the manner of catching and measuring precipitation have been greatly varied. The measuring, of course, is simple enough, but it is far from easy to secure a correct catch, owing chiefly to the influence of the vessel itself on the wind currents over and about its mouth and the consequent effect on the amount of precipitation actually caught. The details of a simple rain gauge are shown in Fig. 8, and its installation in Fig. 1. Many gauges are provided with a small tipping bucket just beneath the spout of the receiving funnel, by which the time of occurrence and rate of each rainfall are electrically recorded at any desired place.

Evaporation.—Evaporation is measured in terms of the depth of a flat layer of water, of area equal to that of the evaporating surface. This, too, like precipitation, has been measured by many kinds of apparatus, some of which have been designed with the view of simulating the surface of leaves, or meeting other special conditions. Many attempts have also been made to find from theoretical considerations a correct equation between rate of evaporation and the various factors upon which it depends, such as shape of surface, extent of surface, temperature of the superficial layer, temperature of the air, humidity, barometric pressure, wind velocity, and anything else that might be considered of importance. A few special cases, such as evaporation from flush circular and elliptical water surfaces at constant temperature and in absolutely stagnant atmosphere, appear to have been completely analyzed.[2] But this work, however ingenious, has contributed very little to the solution of the general problem, because in Nature water surfaces are of irregular outline, and all the factors that control evaporation in such a maze of flux and reflux as to render equation testing and evaluation of constants of doubtful accuracy and value. Evaporation, therefore, like most biological and many other phenomena, must be observed and measured; it cannot be computed very accurately as a function of given conditions.

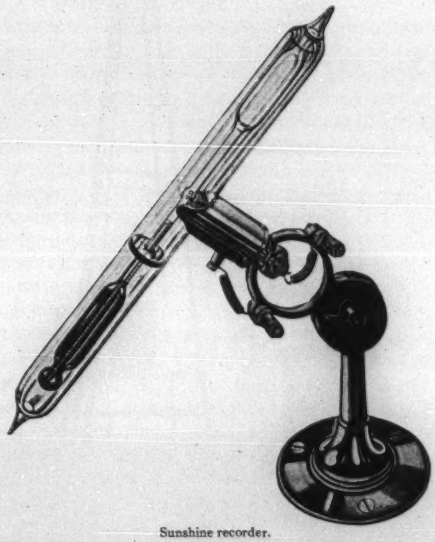
Sunshine.—Sunshine generally is expressed in terms both of

[2] Stefan, *Sitz. der K. Akad.*, 73, 943, 954 (1881).

hours of its actual and percentage of its possible duration. It is recorded automatically, usually through electrical contact made or broken by the movement of a mercury piston in the stem of a vacuum-enclosed black bulb thermometer (Fig. 9); by charring on prepared cards in the focus of a glass sphere; or by photographic traces on sensitized paper.

Radiation.—In relation to the atmosphere, radiation from three sources is of importance: from the sun, from the sky,

FIG. 9.



Sunshine recorder.

and from the earth. Each may be measured integrally (that is, in terms of the amount of energy it delivers per minute, say, per unit normal area at the place of observation), or spectrally (that is, as distributed according to wave-length). The first kind of measurement, the integral, usually is made by some type of pyrheliometer, and the second (so far applied only to solar and sky radiation) by a bolometer.

Electrical Condition.—Measurements of the electrical condi-

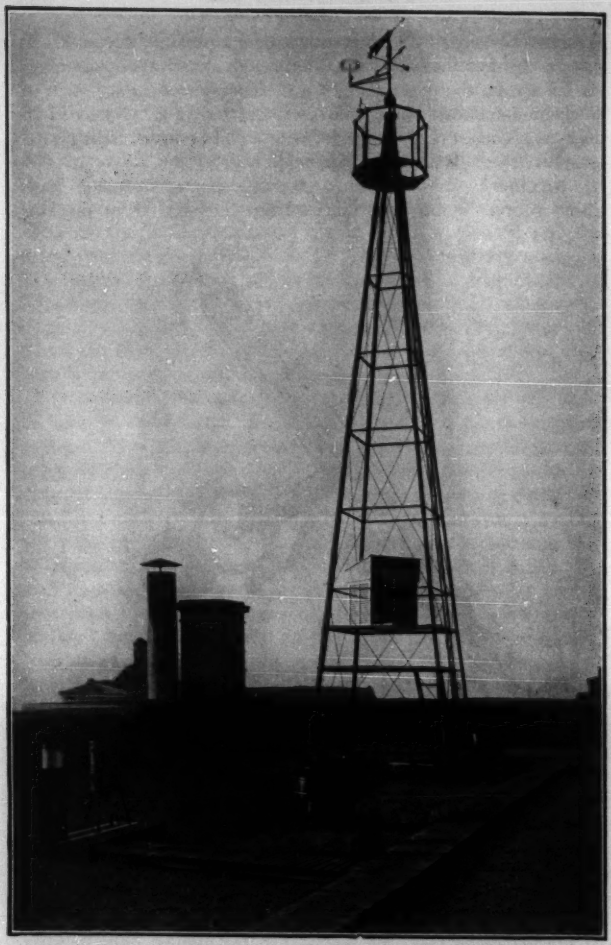


FIG. 10—Forty-foot steel wind instrument tower; typical installation for high office building (Lynchburg, Va., January, 1914.)

tion of the atmosphere generally are confined to the vertical potential gradient, determined by any one of several methods, ionization and the consequent conductivity.

Optical Phenomena.—Various optical phenomena of the atmosphere are observed and recorded. These include, especially, mirages, sky colors, sky polarization, rainbows, coronas, and halos. For several of them—mirages, sky colors, and rainbows—mere eye observations are sufficient. Sky polarization, however, cannot be measured or even detected without the aid of suitable apparatus, while the data pertaining to halos and even coronas are far more valuable when they include accurate angular measurements.

Turbidity.—The turbidity or haze of the atmosphere, whether caused by dust particles (dust haze) or by irregular temperature distribution (optical haze), though often a matter of importance, seldom is measured, and even then only indirectly, since the usual method is to note the maximum distance at which a given object or certain of its details may be distinctly seen. Strictly speaking, this process measures only transparency, from which, however, the inverse, opacity, may be inferred.

Typical Installation.—A typical roof installation of the more common meteorological instruments is shown in Fig. 10. The wind vane is at the top of the tower, the whirling Robinson cup anemometer just below and to the left of the vane, and the sunshine recorder slightly lower, on the cage or platform railing. The thermometer shelter, with the door open, is in the lower portion of the tower. Finally, two rain gauges—one simple, the other tipping bucket—are shown in the lower left corner of the picture.

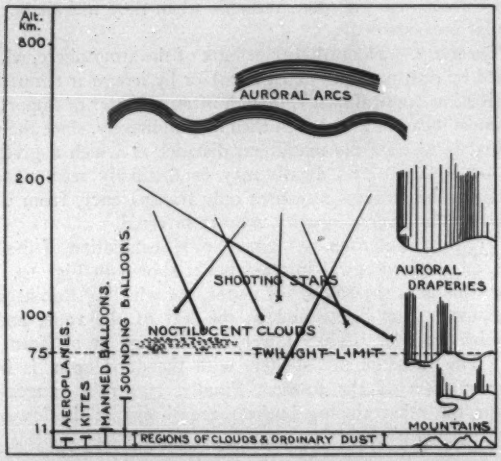
SOURCES OF METEOROLOGICAL INFORMATION.

As a further introduction to a discussion of the physics of the air, it will be helpful to consider a sort of vertical cross-section of the atmosphere as a whole with reference to the *sources* of meteorological information concerning each particular level. Other cross-sections that show its temperature, pressure, and composition at various elevations will be given later. Fig. 11, an adaptation of Wegener's profile of the atmosphere,[3] indicates the principal present sources of this information and the distribution of meteorological phenomena at various levels.

[3] *Phys. Zeitsch.*, 12, Jahrg., 1911, p. 170.

Mountains and other irregularities of the earth's surface make it practicable to examine the atmosphere minutely and to record continuously all its changes at every elevation from sea level up to nearly six kilometres. In fact, many continuous records have already been obtained at the summit station on El Misti, Peru, whose altitude is 5852 metres. Temporary and partial records have been obtained by this means as far up as about 7 kilometres, but no higher, since this is the limit to which any one has ever yet been able to climb. But all such records,

FIG. 11.



Sources of meteorological information.

whether obtained at high levels or low, of course are more or less affected by the surface conditions. Hence some means of obtaining observations and records other than apparatus carried about on the surface of the earth is essential to a knowledge of the conditions and movements of the free atmosphere. One obvious source of information as regards motion only, and which has been extensively used, consists in the observation of clouds, which occur at all levels from the bottom of the atmosphere up to 11 kilometres, or thereabouts, in middle latitudes, and occasionally, in the tropics, even as high as 15 kilometres.

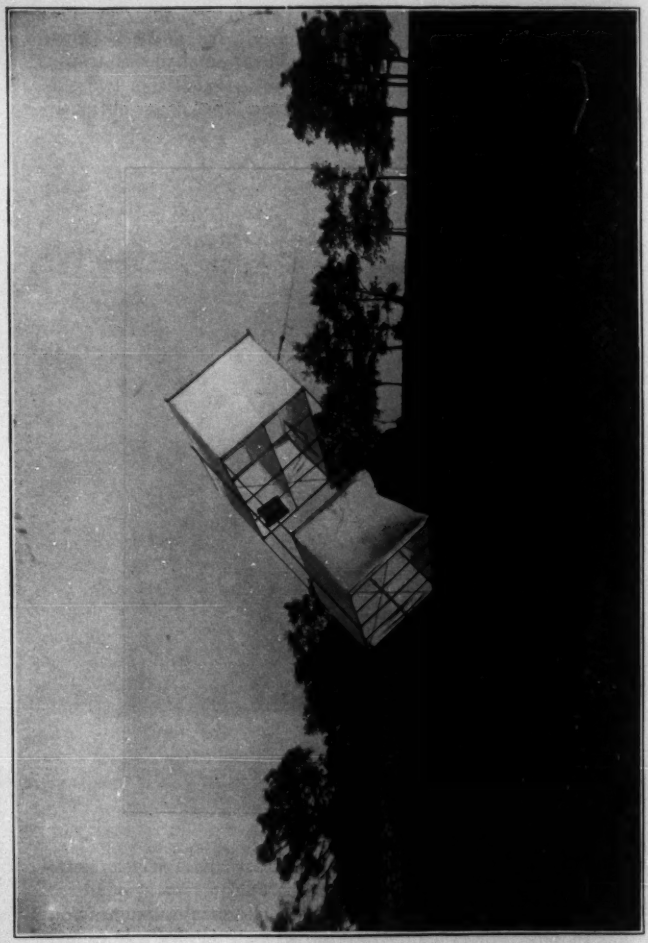


FIG. 12.

Launching meteorological kite, Mount Weather.

There are several methods of determining the elevation, direction of motion, and velocity of clouds, but all depend upon simple processes of triangulation. Thus simultaneous transit observations made on the same spot in a cloud from two stations whose elevations and distance apart are known obviously

FIG. 13.

Sounding balloon.

furnish all the data necessary for an easy and fairly accurate determination of the height of the particular spot in question, while a single subsequent observation by either instrument on this spot, provided the time interval between the first and second observations is known, clearly gives all the additional data neces-

sary to the determination of its velocity and direction of motion. Excellent results, also, are gotten from cloud negatives simultaneously obtained with photographic transits provided with fiducial lines. In this way, if several successive exposures are made, the height and movement of each distinguishable point in the

FIG. 14.

Sounding balloon.

cloud can be determined, and therefore not only the general height and drift of the cloud as a whole, but also its dimensions and something of its internal motions. However, the general motion of the wind at the point observed and time of observation, though interesting and often valuable, practically is all the information about the atmosphere that clouds give, and.

indeed, some, such as those formed by air billows over mountain crests and elsewhere, do not give even this. Besides, they are not always present, so that on clear days even this modicum of information about the upper air would be impossible to obtain if we had no other means of investigation. But there are others, the most fruitful of which is the carrying of self-registering thermometers, barometers, hygrometers, and the like into the free air by means of:

a. Kites (Fig. 12) to over 7 kilometres, the record being 7.26 kilometres.

b. Aeroplanes; present limit about 8 kilometres.

c. Manned balloons; maximum elevation, roughly, 11 kilometres.

d. Sounding balloons (Figs. 13 and 14), with a record of 35.08 kilometres.

e. Pilot balloons, small balloons without apparatus; maximum elevation reported, 39 kilometres.

The registering apparatus sent aloft by these various methods furnishes reliable information concerning the composition (including humidity), temperature, pressure, direction of motion, and, in some cases, velocity of the air, from the surface of the earth up to the greatest elevation reached. And it is this automatically recorded information, gathered, with but little exception, since the beginning of the twentieth century, that has so greatly extended our accurate knowledge of meteorology, and done so much to make of it an interesting and profitable branch of both theoretical and applied physics.

Beyond the reach of the pilot balloon, or, for the present, at elevations greater than 39 kilometres, our information of the atmosphere is limited to such deductions as properly may be drawn from the height of the twilight arch—roughly, 75 kilometres; the paths of shooting stars, rarely, if ever, seen as high as 200 kilometres; and the phenomena of the auroras, those curious and but partially explained electrical discharges that seldom occur at a lower level than 90 kilometres or higher than 300.

The above obviously are all, or nearly all, the means by which our knowledge of the atmosphere has been obtained. Up to 35 kilometres it is comparatively well known, but beyond that level only deductions, growing less certain with increase of elevation, can possibly take us at present, or at any time until higher soundings have been made.

CHAPTER II.

SOME THEORETICAL TEMPERATURE RELATIONS OF THE ATMOSPHERE.

WITH the object of more clearly understanding the causes of the actual distribution of temperature in the atmosphere, it will be convenient, first, to consider some of the thermodynamic equations of gases, especially those that give relations between temperature, pressure, and volume.

If to a unit mass of air or other gas at constant pressure p a quantity of heat dQ be supplied, the energy so added will divide itself into two parts. One portion will change the temperature of the gas and the other will change its volume. Hence, if the work is expressed in its heat equivalent, or if each portion of the energy is expressed in heat units and not in units of work, then

$$dQ = C_v\, dT + A\, p\, dV \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

in which C_v is the specific heat of the gas in question at constant volume, dT and dV the resulting changes in temperature and volume, respectively, and A the reciprocal of the mechanical equivalent of a unit of heat.

But to secure the relations desired, the relation of p to T, for instance, when both are variable, it is necessary to have an additional equation involving dT, dp, and dV. From Boyle's and Charles's laws, we have the equation,

$$pV = \frac{p_0 V_0}{T_0} T,$$

which expresses the fact that for a given quantity of gas the product of pressure and volume varies directly as the absolute temperature, T. So long, then, as the quantity of gas involved and its temperature are constant, so also is the product pV. But when this quantity is one gramme and the temperature o° C., it is convenient to speak of the quantity, $\frac{p_0 V_0}{T_0}$, as the characteristic constant, R, of the gas in question. In general, then,

$$pV = RT,$$

in which the value of R depends solely upon the kind of gas.

Hence, differentiating,

$$p\, dV + V\, dp = R\, dT. \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

To find the relation between dp and dT in an adiabatic proc-

ess (that is, a process in the course of which no heat is either given to or taken from the gas involved, such as closely obtains in the case of rapidly rising or falling air), it is only necessary, by aid of equation (2), to eliminate dV from equation (1) and to put $dQ = 0$.

Thus

$$C_v\,dT + A.(R\,dT - V\,dp) = 0$$

or

$$(C_v + AR)\,dT = AV\,dp. \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Also, since the excess of the specific heat at constant pressure over the specific heat at constant volume is simply the amount of heat necessary to perform the external work incident to expansion as a result of increasing the temperature 1° C., we have,

$C_p - C_v = AW$, the heat equivalent of the external work.

And from $pV = RT$, we get, with p constant,

$$p\,dV = R\,dT.$$

If $dT = 1°$ C., then $Ap\,dV$ is the heat equivalent of the external work done as a result of increasing the temperature of the unit mass of the gas in question 1° C. Hence,

$$C_p - C_v = AR.$$

On substituting this value of R in (3), we get,

$$C_p\,dT = AV\,dp,$$

or

$$\frac{dT}{dp} = \frac{AV}{C_p} = \frac{ART}{pC_p}. \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

From this it appears that the ratio of the change of temperature to the change of pressure, in an adiabatic process, is directly proportional to the absolute temperature and inversely proportional to the pressure.

In the case of dry atmospheric air at ordinary temperatures $C_p = 0.241$, about.[4] Hence,

$$dT = dp\,\frac{ART}{p\ 0.241}.$$

But

$$R = \frac{p_0 V_0}{T_0} = \frac{p_0}{\rho_0 T_0},$$

from which, assuming p_0 to be the pressure in dynes per square centimetre when the barometer under normal gravity and at 0°

[4] Moody, *Phys. Rev.*, 34, p. 275 (1912).

C. stands at 760 mm., and that ρ_0 is the corresponding density of air at 0° C., it follows that, numerically,

$$R = \frac{1033.3 \times 981}{0.001293 \times 273} = 2.871 \times 10^6;$$

and

$$A = \frac{1}{4.19 \times 10^7}.$$

Therefore,

$$dT = \frac{dp}{p} \frac{T}{3.5172},$$

and

$$\frac{dT}{T} = .2843 \frac{dp}{p}.$$

In the special case where the pressure is one atmosphere (barometer reading 760 mm.) and the temperature 0° C. (273° absolute), such as often happens on the surface of the earth, an adiabatic change of pressure represented by 1 mm. of the barometer produces a temperature change given by the equation,

$$dT = \frac{1}{760} \frac{273}{3.5172} = 0°.10213 \text{ C.}$$

From equation (4) we get

$$\frac{dT}{T} = \frac{dp}{p} \frac{AR}{C_p}$$

Hence

$$\log_e \frac{T_1}{T_2} = \frac{AR}{C_p} \log_e \frac{p_1}{p_2}$$

or,

$$\frac{T_1}{T_2} = \left(\frac{p_1}{p_2}\right)^{\frac{AR}{C_p}} = \left(\frac{p_1}{p_2}\right)^{\frac{C_p - C_v}{C_p}} = \left(\frac{p_1}{p_2}\right)^{0.286},$$

or,

$$\frac{p_1}{p_2} = \left(\frac{T_1}{T_2}\right)^{3.50}.$$

If we wish to find the rate of adiabatic cooling with change of elevation, dh, a matter of great meteorological importance, it is necessary to find the value of dp in terms of dh and substitute in equation (4). It must be remembered, too, that the pressure p decreases as the height h increases.

But $-dp = 981\ \rho\ dh$, where ρ is the density of the gas in question, or

$$-dp = \frac{981\ dh}{V} = \frac{981\ p\ dh}{RT}.$$

Hence, by substitution in equation (4), as explained,

$$-\frac{dT}{dh} = \frac{981\ A}{C_p} = \frac{1}{10293} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Clearly, then, when the atmosphere is dry and its temperature decreases with increase of altitude at the above adiabatic rate of 1° C. per 102.93 metres, any portion of it transferred without gain or loss of heat from one level to another has, at every stage, the same temperature and density as the adjacent air, and therefore, if abandoned at rest, will neither rise nor fall. If, however, the temperature decreases with altitude at a less rate than the above, an isolated mass of air, on being adiabatically lifted or depressed, becomes colder and denser or warmer and rarer, respectively, than the adjacent air, and consequently, if abandoned, will return to its initial level. Finally, if the temperature decrease with altitude is more rapid than the above rate, an isolated mass of air, on being elevated or depressed, will become warmer and lighter or colder and denser than the adjacent air, and, if permitted, will continue to rise or fall, respectively, until arrested by a change in the temperature gradient, or, if descending, perhaps even by the surface of the earth.

In short, the atmosphere is in neutral, stable, or unstable equilibrium according as the temperature decrease with increase of altitude is the same as, less than, or greater than the adiabatic rate of 1° C. per 102.93 metres.

From equation (5) it is obvious that the adiabatic rate of temperature decrease of the atmosphere with increase of altitude is independent alike of altitude, temperature, and pressure, unless, possibly, its specific heat at constant pressure may slightly vary with temperature or pressure, or both. When, however, the composition of the atmosphere is changed, it is obvious that its specific heat, and therefore its temperature gradient, must also change. Now the chief variable constituent of the atmosphere is water vapor, and, since its specific heat is approximately 1.6 that of dry air, it follows that the greater the amount of water vapor present the less rapid will be the adiabatic decrease of temperature with increase of altitude.

Water vapor also frequently causes another and most important change in the temperature gradient. As soon as condensation sets in the latent heat of vaporization, and, if ice is formed, of fusion, is liberated, and thus the rate of temperature decrease with altitude is reduced. The amount of this reduction, often at least half the original value, depends, of course, slightly upon what becomes of the condensed vapor. If it is carried along with the rising air the process remains adiabatic, except as slightly modified by conduction and radiation, but if, as in great measure must happen, it is left behind as precipitation, then the process becomes that special case of the nonadiabatic which von Bezold, followed by others, has called pseudoadiabatic. This whole subject has been more or less discussed by several writers, but most fully, first, by Hertz [5] and, later, by Neuhoff.[6]

Undoubtedly much of the condensation drops out, or begins to drop out, as soon as formed, so that the actual temperature gradient, while lying somewhere between the really adiabatic and the "pseudoadiabatic" curves, probably follows the latter more closely than the former. Presumably, therefore, in practice it would be better, or at least quite as well, to determine the latter gradient (the adiabatic will be considered later, under "Condensation," in the chapter on "Humidity") and then to add such corrections to it as the circumstances of individual cases suggest. The main curve can be determined as follows:

As before,

$$dQ = C_v\, dT + A p\, dv.$$

But

$$pV = RT, \text{ (R being appropriate to the existing mixture of air and water vapor).}$$

Hence

$$\begin{aligned} dQ &= C_v dT + A(R\, dT - V\, dp) \\ &= (C_v + AR)dT - A\, V\, dp \\ &= C_p dT - A\, V\, dp \end{aligned}$$

But

$$-dp = g\rho dh,$$

where g is gravitational acceleration.

Therefore,

$$dQ = C_p dT + g\, A\, dh.$$

[5] *Deutsch. Met. Zeit.*, vol. i, 1884, p. 421.
[6] *Abh. d. K. P. Met. Inst.*, vol. i, No. 6, Berlin, 1900.

Now the heat, dQ, is added as the result of a quantity of water vapor, dw, being extracted. Hence

$$dQ = -s\,dw,$$

in which s is the heat of vaporization, and therefore,

$$-s\,dw = C_p dT + g\,A\,dh.$$

From this equation it is obvious that to obtain the ratio of dT to dh in terms of measurable quantities it is necessary and sufficient to express dw in similar terms.

But

$$w = \rho\, 0.622\, \frac{e}{b},$$

in which w is the total mass of water vapor per cm.,[3] ρ the density of the air, 0.622 the ratio of the molecular weight of water vapor to the weighted mean of the molecular weights of the constituents of dry air, e the partial pressure of the water vapor in terms of millimetres, say, of mercury, and b the height, in millimetres, of the barometer.

Hence

$$\frac{dw}{w} = \frac{de}{e} - \frac{db}{b}.$$

But, if D is the density of mercury,

$$-D\,db = \rho\,dh = \frac{p\,dh}{RT} = \frac{D\,b\,g\,dh}{RT}$$

Hence

$$-\frac{db}{b} = g\,\frac{dh}{RT}.$$

and

$$dw = w\frac{de}{e} + wg\,\frac{dh}{RT}.$$

Hence, by substitution,

$$C_p\,dT + sw\frac{de}{e} + swg\,\frac{dh}{RT} + gA\,dh = 0$$

or

$$\left(C_p + sw\frac{de}{e\,dT}\right)dT + \left(\frac{sw}{RT} + A\right)g\,dh = 0$$

and

$$\frac{dT}{dh} = -\frac{g\left(A + \frac{sw}{RT}\right)}{C_p + sw\,\frac{de}{e\,dT}} \qquad (6)$$

All the terms on the right-hand side of this equation are known for any definite temperature and assumed value of dT. From this equation, therefore, tables can be written and curves constructed that give the "pseudoadiabatic" gradient under all conditions of temperature and pressure.

CHAPTER III.

OBSERVED VERTICAL TEMPERATURE GRADIENTS.

THE temperature of the surface air is well known at many places and at various altitudes, from sea level up to about six kilometres. But the temperature records obtained by the aid of kites and balloons, both manned and free, show that the mountain air temperatures generally differ materially from the temperature of the free air at the same elevation and latitude.

According to Hann,[7] the average temperature of the surface decreases approximately at the rate of 1° per each 180 metres, 200 metres, and 250 metres increase of elevation on mountains, hills, and plateaus respectively. In the free atmosphere, however, the result is quite different. Here the decrease of temperature with increase of altitude, except at very great elevations, is, roughly, the same at different parts of the world.

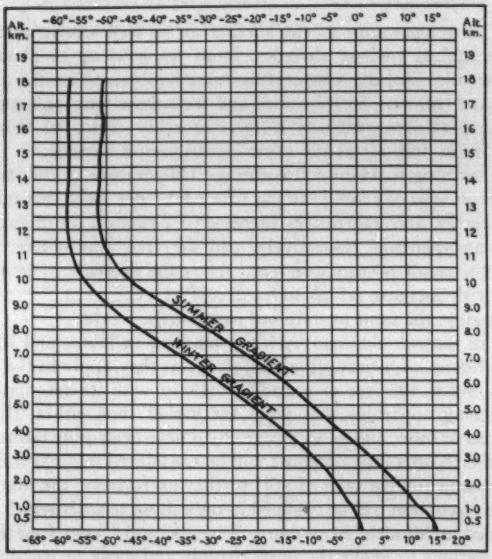
The records obtained by kites, manned balloons, and sounding balloons, of course, all agree, so far as they apply to the same levels, but as the free or sounding balloon, with its automatically registering apparatus, has gone far higher than either manned balloons or kites, and as ascensions by it have been quite numerous, only the records thus obtained will be considered in what follows. Again, and for the sake of still further uniformity, the first part of the discussion will be confined to only those records which were obtained at Munich, Strassburg, Trappes, and Uccle, four European stations of about the same latitude and more or less similar climates. It seems also desirable to divide the records of vertical temperature distribution according to season, winter (December, January, February, and March) and summer (June, July, August, and September), and prevailing type of weather, or, to be more exact, the height of the barometer, high, low, and neutral. Spring and fall observations will not be used in the typical or most general temperature distributions, owing to the

[7] "Lehrbuch der Meteorologie," 3d ed., p. 126.

transitional nature of these seasons, or the overlapping and confusion at these times of summer and winter conditions.

At the time these data were assembled, the early part of 1910, all the published records of the stations mentioned were used, there being 52 winter records and 65 summer records. A larger number of flights would, of course, furnish a somewhat more reli-

FIG. 15.



Winter and summer vertical temperature gradients.

able average, but, as the several stations gave substantially the same results, it would seem that no great change would be made in the season averages, however large the number of combined observations.

Fig. 15 gives the average winter and summer vertical temperature gradients of the stations in question, or the graphs obtained by plotting the average of the observed temperatures

of the given season against the corresponding altitudes at which they were obtained.

A number of interesting points are brought out by these two curves, each of which calls for an explanation. Among other things, the two gradients are, roughly, parallel to each other throughout their whole range. This is because the temperature of the atmosphere from top to bottom is determined by the same factors in the winter that determine it in the summer; that is, by radiation, conduction, and convection, all mainly from the surface of the earth and the lower atmosphere. Since all these factors are less in winter than in summer, it follows that their combined result, the temperature of the higher atmosphere, must also be less at every level; hence the substantial parallelism of the two gradients.

Again, it appears, as shown by the figure, that up to about 2½ kilometres the temperature decreases less rapidly with increase of elevation during winter than it does during summer. The reason for this, while not quite obvious, will become apparent from the following considerations:

The surface of the earth, which is a much better radiator than the atmosphere, often cools, especially during clear nights, to a decidedly lower temperature than the air 100 metres or so above it. Hence late at night, when the sky is clear and there is no wind, the temperature near the surface usually increases with increase of elevation, and even when there is sufficient wind to prevent this "temperature inversion," as it is called, the lower atmosphere still is colder than it otherwise would be. Obviously, too, the amount of this surface cooling, and therefore the magnitude of the temperature inversion, depends jointly upon the rates of radiation to and from the sky and the time involved. Now the rate of the output of surface and lower air radiation is less in winter than in summer, both because of their lower temperatures at that time and because the atmosphere then contains less water vapor, its chief radiating constituent. Hence, although, owing to higher temperatures, both the radiation loss from the surface of the earth and adjacent air and their radiation gain from the upper air are greater in summer than in winter, the difference, or net loss, may usually be less.

At any rate, partly for this reason, it may be, but mainly because of the relatively greater length of the nights and greater

dryness and consequent diathermacy of the atmosphere, the total surface cooling, and therefore the morning temperature inversions, is much more pronounced in winter than in summer. Hence the average decrease of temperature with increase of elevation through the first one or two kilometres is decidedly less during the colder than during the warmer season.

Another peculiarity shown by the curves is the fact that between the elevations of approximately four and eight kilometres the temperature decreases rather more rapidly during winter than summer. Throughout this region the temperature of the atmosphere depends in part upon convection from lower levels and in part upon its gain and loss of heat through radiation. But even this midair, or radiational, change in temperature can result only in immediate convection. Consequently, so long as saturation is not reached, the convectional temperature gradient must be very approximately that of a totally dry atmosphere. If, however, condensation takes place, the latent heat of vaporization becomes sensible heat, and the decrease of temperature with increase of altitude is correspondingly less. When a condensation temperature gradient is once established in this mid-region of the atmosphere it tends to persist, even after condensation has ceased and the clouds have evaporated, because, whatever condition—the presence or absence of sunshine, for instance—produces a temperature change in one part of it is likely to produce similar temperature changes in other parts, and therefore a dry air adiabatic variation for each level, a variation which would leave the general temperature gradient substantially as before. We should, then, expect to find the average vertical temperature gradient following, roughly, the gradient for saturated air for the given temperature, and such, indeed, are the gradients actually found.

Hence, as the atmosphere between the elevations of four and eight kilometres is quite out of the reach of surface inversions, and as it is also warmer and more humid during summer than during winter, we should expect the summer temperature of this region to decrease less rapidly with increase of altitude than does the winter temperature, precisely as balloon records show to be the case.

Another point brought out by Fig. 15 is the fact that up to eight kilometres, or thereabouts, the ratio of the decrease of temperature to increase of altitude itself increases with altitude. The

explanation of this phenomenon is precisely the same as that of the difference between the winter and summer gradients from four to eight kilometres. That is to say, it depends upon the amount of water vapor necessary to produce saturation at the various levels, since the less this vapor is in proportion to the total gases present the more nearly does the actual temperature gradient follow the adiabatic curve for dry air.

One striking feature of each of the temperature gradients is its gradual change, between the levels of nine and twelve kilometres, from a rapid decrease of temperature with increase of elevation to an approximately isothermal condition. Normally, however, the temperature gradient changes from a rapid to practically a zero decrease, and even, as usually recorded, to a slow increase of temperature with increase of elevation, much more abruptly than one would infer from the given curves. But this more or less abrupt change varies considerably in altitude from day to day. Therefore, when a large number of actual gradients are averaged an *apparent* gradual transition is indicated.

Two other features calling for some attention are shown by the lower portion of the summer gradient; namely, the fact that through the first half kilometre the temperature decreases but slowly, and the further fact that through the second half kilometre it decreases more rapidly than anywhere else, short of very considerable altitudes. Now nearly all the observations from which this summer gradient was constructed were obtained during the early forenoon. Hence the average slow decrease of temperature with increase of elevation is the result only of ordinary morning inversions. On the other hand, the rapid decrease of temperature through the second half kilometre is expressive of the adiabatic gradient of unsaturated air that commonly exists during summer afternoons up to a level of at least one kilometre. In this case it has persisted in its upper portion throughout the night, and been modified, as explained, by temperature inversions only in its lower half.

CHAPTER IV.

THE ISOTHERMAL REGION, OF STRATOSPHERE.

OF all the conditions indicated by the temperature gradients of Fig. 15, by far the most surprising, and most difficult fully to explain, is the approximately isothermal state of the upper

atmosphere. Indeed, the discovery of the fact that the temperature of the upper atmosphere changes but little with altitude, and the supplementary discovery of its physical explanation, constitute one of the most important advances in modern meteorology.

The exploration of the atmosphere by small balloons carrying meteorological instruments was suggested in 1809,[8] but the idea was first carried out by Hermite[9] on March 21, 1893, when an elevation of 16 kilometres was attained. In April, 1898, Teisserenc de Bort,[10] with improved apparatus, began at Trappes, France, a long series of frequent atmospheric soundings. Among other things, he soon found temperature records that indicated something unsuspected: either errors in the thermometers themselves or surprising temperature conditions in the upper atmosphere. However, numerous temperature records subsequently obtained by himself and many others in various countries and with different kinds of apparatus have shown that, in general, the temperature of the upper atmosphere actually does change but little with change of elevation. Indeed, as a rule, the change is so small that the whole region characterized by this approximate constancy of temperature has been called the " isothermal region." At present it is more generally known as the "stratosphere," though the older and less used term certainly is more suggestive of its distinguishing characteristic.

The height at which this region begins and its temperature both depend upon season, upon storm conditions, and upon latitude; but, while all these are important details, they are secondary to the fact that there is an isothermal region at all.

As soon as observations left no doubt of the actual existence of the isothermal region many explanations of it were proposed, but for a number of years all such suggestions proved unavailing. Finally, however, independently and nearly simultaneously, the generally accepted explanation occurred to Gold[11] of England and Humphreys[12] of America. The same subject has also been discussed at length by Emden.[13] The key to the explanation is this: The temperature of every portion of the atmosphere is

[8] *Ann. Harvard Obs.*), **68**, pt. 1, p. 1.
[9] *L'Aérophile*, 1, p. 45 (1893).
[10] *C. R.*, 129, p. 417 (1899).
[11] *Proc. Roy. Soc.*, series A, vol. 82, 1909, p. 43.
[12] *Astrophys. Jour.*, vol. 29, 1909, p. 14.
[13] *Sitz. der K. Bayr. Akad. der Wis.*, Jahr., 1913, p. 55.

determined, in part at least, by counteracting radiation—radiation absorbed and radiation emitted—and wherever these two are equal there is substantial constancy of temperature.

Mr. Gold's method of procedure was to take the best-known data concerning atmospheric absorption and radiation and to obtain, by the aid of suitable mathematics, a general solution of the problem. The chief difficulty in the application of this direct and elegant method, apart from the troublesome equations involved, is due to our imperfect knowledge of the necessary radiation and absorption constants. Numerical values in these particulars are not accurately known and certainly not easy to determine.

On the other hand, the solution offered by Humphreys, while not so direct, reduces the necessary mathematics to a minimum. In brief, it is as follows: Since the average yearly temperature of the atmosphere at any given place does not greatly change, it follows that the absorption of solar radiation by the earth as a whole is substantially equal to the total outgoing earth radiation, and in amount approximately equal to that which a black or perfectly radiating surface, equal in area to the surface of the earth would emit if at the absolute temperature 259° C.[14] Further, since at ordinary atmospheric temperatures water vapor, in any considerable quantity, absorbs and, presumably, also radiates substantially as does a black body at the same temperature, while dry air is exceedingly diathermanous, it follows that the planetary radiation of the earth is essentially water vapor radiation.

Now the records of sounding balloons show that at some altitude, in general about 11 kilometres above sea level in middle latitudes, the average temperature ceases to decrease with increase of elevation. Individual flights show many peculiarities that call for special explanation, but the purpose here is to consider only the general explanation of the main effect, and therefore average conditions are considered.

If, then, as is approximately true, the temperature does not decrease with increase of altitude above 11 kilometres, it follows that this must be the limit of anything like a marked vertical convection. And from this in turn it follows, since conduction is negligible, that the upper atmosphere must be warmed almost wholly by absorption of radiation, in part solar and in part ter-

[14] Abbot and Fowle, *Annals of the Astrophysical Observatory of the Smithsonian Institution*, vol. 2, p. 174.

restrial; but exactly how much of the final temperature of the upper atmosphere is due to the one source of heat and how much to the other it is not possible to say. However, there are certain facts that seem clearly to indicate the relative importance in this respect of the two sources. Thus the summer and winter gradients as given by Fig. 15 show a difference of temperature in the isothermal region of only about the amount that might be expected on the assumption that the temperature of the upper air is wholly dependent upon the radiation from the lower. That is to say, the seasonal temperatures of the lower atmosphere differ distinctly more than do those of the upper. It should be clearly kept in mind, too, that the particular seasonal gradients given in Fig. 15 were obtained at a latitude of, roughly, 50 degrees, where the number of hours of summer and winter sunshine differ greatly, and therefore where the seasonal temperature of the isothermal region, if essentially determined by absorption of solar radiation, should differ somewhat correspondingly. But, as no such great difference in these temperatures exist, it would appear that the temperature of the isothermal region must be chiefly due to absorption of long wave-length radiation given off by the water vapor and other constituents of the atmosphere at lower levels, and to only a very minor degree to the absorption of solar radiation. Hence, as a first approximation, one may consider this radiation alone, and for the lower atmosphere as it actually exists substitute the radiationally equivalent black shell at the absolute temperature of 259° C. Obviously, too, this surface, surrounding as it does the entire earth, may be regarded as horizontal and of infinite length and breadth in comparison to any elevation attainable by sounding balloons.

Now consider two such surfaces, parallel and directly facing each other, with distance apart small in comparison to their width, and having the absolute temperature T_2, and let an object of any kind whatever be placed at the centre of the practically enclosed space. Obviously, according to the laws of radiation, the final temperature of the object in question will also become approximately T_2. If, now, one of the parallel planes should be removed, the uncovered object would be in substantially the same situation, so far as exposure to radiation is concerned, as is the atmosphere of the isothermal region in its exposure to the radiation from the lower atmosphere. Of course, each particle

of the upper air receives some radiation from the adjacent atmosphere, but this is small in comparison to that from the lower water vapor and may, therefore, provisionally be neglected. Hence the problem, as an approximation, is to find the final temperature to which an object, assumed infinitesimally small, to fit the case of a gas, will come when exposed to the radiation of a single black plane.

In each case—that is to say, when between the parallel planes and when facing but one—temperature equilibrium is reached when the loss of energy by radiation is equal to its gain by absorption. Also, so long as the chemical nature of the object remains the same, its coefficient of absorption is but little affected by even considerable changes in temperature. Therefore, whatever the nature of the object, since it is exposed to twice as much radiation when between the two planes as it is when facing but one, it must, in the former case, both absorb and emit twice as much energy as in the latter. Or, using symbols,

$$E_2 = 2E_1$$

in which E_2 and E_1 are the quantities of heat radiated by the object per second, say, when between the two planes and when facing but one, respectively.

Again,

$$E_2 = K_2 T_2^{n_2}$$

and

$$E_1 = K_1 T_1^{n_1}$$

in which T_2 and T_1 are the respective absolute temperatures of the object under the given conditions, and K and n the radiation constants.

For every substance there are definite values of K and n, which, so long as the chemical nature of the object remains the same, do not rapidly vary with change of temperature. Hence, assuming $K_2 = K_1$ and $n_2 = n_1$, we have from the equation

$$E_2 = 2E_1$$

$$T_2 = \sqrt[n]{2}\ T_1$$

From this it appears that there must be some minimum temperature T_1 below which the radiation of the lower atmosphere will

not permit the upper atmosphere to fall, though what it is for a given value of T_2 depends upon the value of n.

Presumably the radiation of the upper atmosphere is purely a thermal radiation, and therefore in full agreement, as is the thermal radiation of water vapor, carbon dioxide, and certain other gases, with the Kirchhoff [15] law. In other words, the ratio of emission to absorption for any given wave-length, presumably, is wholly a question of temperature, and is numerically equal to the radiation of a black body at the same temperature and wave-length. In symbols,

$$\left(\frac{He}{h}\right)_{\lambda,\, t} = (E)_{\lambda,\, t}$$

in which H is the incident energy, h the energy absorbed, and e the energy emitted by the body or gas in question at the wave-length λ and temperature t, and E the black body emission at the same wave-length and temperature, all per equal area and time.

To fix the ideas, let the body of gas under consideration be a shell one centimetre thick, surrounding the earth at a fixed distance—20 kilometres, say, above sea level—and let the black body be a very thin shell at the same temperature inside and outside, that may, if we wish, take the place of the gas shell. Now, since nearly all the incident radiation under consideration, the radiation of the earth and its atmosphere onto a shell at 20 kilometres elevation, or anywhere else in the isothermal region, comes from below, we may assume it, or its normal equivalent, to be substantially the same for all levels of the upper atmosphere, and assume the emitted radiation to be all the energy sent out by the shell on *either* or on *both* sides; only, whatever the assumption for one shell, the same must be made for the other.

Returning to a consideration of the temperature of the upper atmosphere under the influence of radiation from the lower gases: Since the composition of the upper atmosphere is not appreciably changed by a change of even 50° C., it follow that such a change of temperature will not materially alter its coefficient of absorption. Hence a change in the intensity of the incident radiation H will make substantially the same proportionate change in the rate of absorption h, whatever the alteration in temperature. In short,

[15] Pringsheim, *Congrès International de Physique*, Paris, 1900, vol. 2, p. 127.

$$\frac{H}{h} = K \text{ a constant, presumably.}$$

Hence

$$\frac{e_{\lambda, t_1}}{e_{\lambda, t_2}} = \frac{E_{\lambda, t_1}}{E_{\lambda, t_2}}$$

or

$$\frac{e_{\lambda, t_1}}{E_{\lambda, t_1}} = \frac{e_{\lambda, t_2}}{E_{\lambda, t_2}}$$

Unfortunately, nothing is known of the spectral distribution of the energy radiation of the cold upper atmosphere, though possibly it is of the irregular, but more or less continuous broad band, type. If this is its distribution, and if for each wave-length the increase of black body radiation, for a small increase of temperature, is proportional to the total radiation at that wave length, which it is to a rough first approximation, then to about the same average approximation,

$$\frac{e_{t_1}}{e_{t_2}} = \frac{E_{t_1}}{E_{t_2}}$$

in which the symbols stand for the total radiation of all wave-lengths.

But from the Stefan law in regard to the total radiation of black bodies, we know that

$$\frac{E_{t_1}}{E_{t_2}} = \frac{T_1^4}{T_2^4}$$

in which T_1 and T_2 are the respective absolute temperatures.

Hence, as explained above, if the spectral distribution of the radiation of the upper atmosphere is continuous, or nearly so (no matter how irregular), and not confined chiefly to lines with zero radiation between them, it follows that in the equation,

$$T_2 = \sqrt[n]{2}\, T_1$$

the numerical value of n must be 4, roughly. But, as already explained, the value of T_2 is substantially 259° C. absolute; hence, on the assumption that $n = 4$, it follows that $T_1 = 218°$ C. absolute. And this is the value, approximately, that observation gives.

Whatever the facts in regard to the radiation constants of the atmosphere, the laws of radiation and absorption demand that the temperature of the upper atmosphere shall change but little with change of elevation. Besides, while the exact value

of this temperature—the temperature of the isothermal region—is, of course, best determined by actual observation, it also may be computed approximately from the known intensity of outgoing radiation, together with the thermal properties of the gases of the atmosphere.

Doubtless solar radiation affects the temperature of the isothermal region to some extent, but, presumably, not very much, since the radiation from the lower levels seems competent not only to produce an isothermal condition in the upper levels, but also to maintain them at substantially the observed temperature. Further, the lower atmosphere obviously is slightly warmed and its radiation correspondingly increased by return radiation from the upper, but this presumably does not affect the general validity of the above reasoning, which is based on the action of the *total* outgoing radiation.

Given the isothermal condition of the upper atmosphere, it follows that the heated surface air can, under favorable circumstances, rise till, but only till, by expansion it has cooled down to that temperature (the temperature of the isothermal region) below which the radiation from the lower atmosphere will not allow it to fall.

The existence of an upper isothermal region and the vertical temperature gradient (Fig. 15) suggest rational explanations of a number of otherwise obscure meteorological phenomena—why the clouds of a given region have a fairly well-defined maximum elevation; why this elevation is greater in summer than in winter; why it is a level of maximum cloud formation, and the like—but all these are special phenomena that will be discussed independently later on.

(*To be continued.*)

MAINTAINING PHOTOGRAPHIC STANDARDS.*

BY

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PHOTOGRAPHY is so generally practised by technical workers that it is thought a description of the methods employed for the determination and upkeep of the quality of light-sensitive materials may prove interesting. No doubt many workers have seen marked on the packages of photographic plates and films certain numbers that are intended as an indication of the speed of the emulsion. These numbers may be expressed as Hurter and Driffield, Watkins or Wynne values, and I shall endeavor in this paper to describe just how these speed readings are determined and precisely what they mean. Shortly after the introduction of the gelatine dry plate it was customary to express the speed of an emulsion as X-times, which meant that it was X-times the speed of a wet collodion plate. Such speed readings naturally had no real meaning, as they were based upon a variable factor. In the early days of dry-plate photography a well-known photographic worker, Leon Warneke,[1] introduced a sensitometer consisting of a series of numbered squares with increasing quantities of opaque pigment. The plate to be tested was placed in contact with this and an exposure made to the light emanating from a tablet of luminous paint which had previously been excited by exposure to a fixed length of burning magnesium ribbon. After development and fixation the last visible number was taken as expressing the speed of the plate.

The chief objections to this method were that no two numbered plates agreed in density, and the light emitted by the luminous surface varied considerably between its excitation and the exposure of the plate. Furthermore, the pigmented squares possessed selective spectral absorption. It is not uncommon in these days to see plates marked upon the old Warneke system. The

* Communicated by the Author.

[1] Warneke, *British Journal*, 1881.

Seed plates—23 and 27—are instances of this. It is here implied that for the same standard exposure these two Seed emulsions would show as the last visible squares Numbers 23 and 27 respectively. Later Chapman-Jones [2] introduced a modified Warneke sensitometer with a series of 25 graduated densities, a series of four colored squares and a strip of neutral gray, all five being of the same luminosity, and a series of four colored squares, each passing a definite portion of the spectrum. This plate tester was used with a standard candle as a light-source and is still in use for rough estimations of the speed and color sensitiveness of plates. Various other methods more or less similar in principle have been tried, but none have proved practical.

In 1890, two English scientists, Doctor Hurter and Mr. Driffield, published a paper, entitled "Photochemical investigations," [3] which dealt with the chemical, physical, and mathematical principles underlying a scientific system of testing the speed and other characteristics of photographic emulsions. Since Hurter and Driffield's time many investigators have worked on the system and contributed towards its perfection. In connection with the testing of emulsion speeds there are several terms and definitions which must be thoroughly understood. The most important are opacity, transparency, and density. Opacity is the optical property of a substance (in our case silver) to impede the passage through it of light. In other words, opacity is the supression of light or its absorption by the silver image. Transparency is the inverse of this, and is measured by that fraction of the original light which the silver image transmits. For substances which do not reflect much light, such as a thin layer of India ink or a layer of reduced silver deposited as a black substance in negatives, the relation between the quantity of the substance present and the light absorbed is quite simple. If we hold a screen in the form of a thin layer of dilute India ink between the eye and a light-source the layer of India ink absorbs light and therefore reduces the intensity of the light transmitted. Supposing that such a layer absorbs one-half of the incident light, naturally one-half of the light will be transmitted, and, whatever may be the intensity of the original light, the intensity after passing through the India-ink layer will be one-half of what it originally

[2] Chapman-Jones, *Photographic Journal*, 1901.
[3] Hurter and Driffield, *Jour. Soc. Chem. Ind.*, 1890.

was. Two such layers of ink will reduce the incident light to one-fourth its original intensity, and any number of layers will reduce the intensity of the light to a fraction which is equal to the remnant of light the first layer passes, but raised to a power the index of which is the number of layers employed. Thus if n layers were employed and the first one reduced the intensity of the incident light to a fraction $\frac{1}{m}$, then n layers would reduce it to $\left(\frac{1}{m}\right)^n$. If in place of using several successive layers, the first layer is made to contain as much India ink as the n successive layers contain altogether, we shall find that the one layer has the power of reducing the intensity of the light transmitted by exactly the same amount as the n layers do. The reduction of the intensity of the original light is due to the absorption of light by the black particles, and is governed simply by the number of them which are interposed in a given area. Thus we find that the number of layers can be replaced by the number of particles, and the rule can be stated in this form—the intensity Tx of light after passing A particles of a substance is a fraction of the original intensity T, such that $\frac{Tx}{T} = \left(\frac{1}{C}\right)^A$. For mathematical reasons the fraction $\frac{1}{C}$ is generally expressed as a negative power of the base of the hyperbolic logarithms e, so $\frac{1}{C} = e^{-k}$, and we can write $\frac{Tx}{T} = e^{-kA}$. The symbol k is adopted for the coefficient of absorption, then the fraction $\frac{Tx}{T}$ represents and measures the transparency of the substance, and the inverse of this is $\frac{T}{Tx} = e^{kA}$ and measures the opacity of the substance and indicates the intensity of light that must fall on one side of the substance in order that a given intensity may be transmitted. The letter T is used to denote transparency and O opacity.

Density is frequently confused with opacity. By density is meant the number of particles of a substance spread over a given area. In our case it is the relative quantity of silver deposited per unit area multiplied by the coefficient of absorption; kA is what is termed density, and its symbol is the letter D.

The laws of transmission and absorption in connection with a layer of India ink also hold good for a layer of reduced silver,

such as exists in a negative, hence it will be seen that density as applied to photographic negatives is directly proportional to the amount of silver deposited per unit area and may be used as a measure of that amount. The relations existing between the three terms, opacity, transparency, and density, are as follows:

$$O = \epsilon^D$$
$$T = \epsilon^{-D}$$
$$D = \log_\epsilon O = -\log_\epsilon T.$$

In theoretical considerations, such as those dealt with above, Napierian logs are used, but in practical sensitometry common logarithms are used. The full relation existing between opacity, transparency, and density, and also the terminology generally adopted in practical sensitometry, are shown in Fig. 1. By a consideration of these definitions we are in a position to trace the connection between the densities of a theoretically perfect negative and the light intensities which formed them. Density is the logarithm of the opacity, and since, in a theoretically perfect negative, opacities are directly proportional to the intensities of the light which produced them, it follows that each density must be proportional to the logarithm of the light intensity which produced it, or, more correctly, density is a linear function of the logarithm of the intensity of light and time of exposure. Therefore, in a theoretically perfect negative the amounts of silver deposited in the various parts are proportional to the logarithm of the intensities of light proceeding from the corresponding parts of the original object. The practice of a system of emulsion speed measuring is based on the inter-relation of the before-mentioned definitions. To apply these practically in plate-speed measurements four instruments are required:

1. Some form of standard light for making the exposures.
2. An exposing machine used in conjunction with the standard light for impressing the plates with a series of known exposures.
3. A thermostat for maintaining the developing solutions at constant temperature.
4. Some form of photometer for reading the densities of the plates made in the exposing machine.

Standard Lights.—Hurter and Driffield, in their investigations, used the English standard candle. The great objection to this is its spectral composition; candle light is decidedly orange-red; for non-color sensitive plates this may be used, but with yel-

low or red sensitive plates the speed readings obtained would be absolutely wrong. The readings would be five or six times the true speed. In Germany the Hefner amyl-acetate lamp is generally used; in England the Vernon-Harcourt pentane lamp. Un-

F.G. 1.

$$O = \frac{\textit{Intensity Incident Light}}{\textit{Intensity Transmitted Light}} = \frac{I}{I_t}$$

$$T = \frac{\textit{Intensity Transmitted}}{\textit{Intensity Incident}} = \frac{I_t}{I}$$

$$D = -\log_{10} T = \log_{10} O$$

$$I \div O = I_t \text{ or } I \div I_t = O$$

Putting $\frac{I}{I_t}$ into logs gives

$$\log I - \log I_t = \log O = D = \textit{Density}$$

For instance when a plate transmits half the incident light.

$$I \div I_t = \textit{Opacity}$$

$$100 \div 50 = 2$$

$$\text{Log } I - I_t \text{ log} = \log O = \textit{Density}$$

$$\log 100 = 2.000$$

$$\log 50 = 1.699$$

$$0.301 = D = \textit{Density}$$

I		I_t	T	O	D
100		100	1	0	0
100		10	.1	10	1
100		1	.01	100	2
100		.1	.001	1000	3

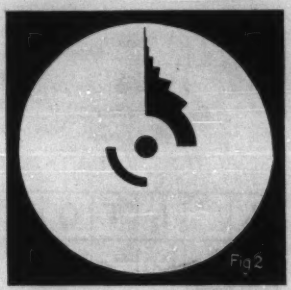
$$\textit{log } I - D = \textit{log } I$$
$$\textit{log } I_t + D = \textit{log } I.$$

doubtedly the most satisfactory light-source is acetylene; a special burner is used giving a long, cylindrical flame. The burner is surrounded by a circular metal chimney which has a small, rectangular opening fitted with a cone that extends to within three millimetres of the surface of the flame; thus only a small portion

of the flame is used, and by always keeping the gas pressure constant by means of a manometer, and the height of the flame the same, the intensity of the light does not vary one per cent. This acetylene light is calibrated to a standard candle. In front of the rectangular opening in the metal chimney is placed a special blue-violet filter that reduces the spectral composition of the acetylene to practically the same as daylight.

Exposing Instruments.—Various instruments for impressing a graduated series of exposures on a plate have been proposed, and they may be divided into two classes, depending on whether a time or an intensity scale is used. Intensity scales usually consist of a sheet of glass covered with squares of pigmented gelatine

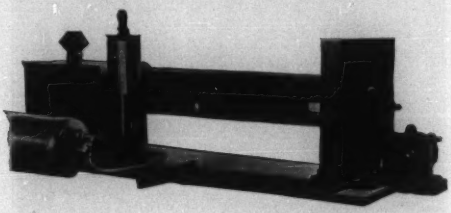
FIG. 2.



transmitting known amounts of light; thus in the Warneke sensitometer previously described each square transmits one-third less light than the preceding. The Chapman-Jones sensitometer is another example of an intensity scale; in practical sensitometry intensity scales are seldom used. Time scales may be impressed by intermittent or continuous exposure. For many reasons continuous exposures are most to be desired, but in practice it has been found difficult to construct a suitable instrument. A time scale impressed by intermittent exposure is easily obtained with a sector wheel having a series of angular openings of the following values: 180, 90, 45, 22.5, 11.25, 5.625, 2.812, 1.406, and 0.703 degrees; each aperture passes twice as much light as the preceding one and gives double the exposure. The sector wheel

is revolved during the exposure in front of, and as near as possible to, the sensitive plate. For negative emulsions it is usual to expose for 40 candle-metre-seconds, and, as the largest angle on the wheel is 180 degrees, it is obvious that an exposure of 80 c. m. s. must be given to obtain an effective 40 c. m. s. The form of the wheel is shown in Fig. 2. In order to do away with the inconvenience of working in a dark room and to avoid troublesome reflections, the sector wheel is enclosed in a box 12 inches by 12 inches by 2 inches. At the back of the box are fitted grooves to carry the plate-holder. The complete instrument is shown in Fig. 3. A pulley is provided by means of which the wheel can be rotated during the exposure of the plate; a small 1/15-horsepower motor geared down to 50 revolutions a minute is used.

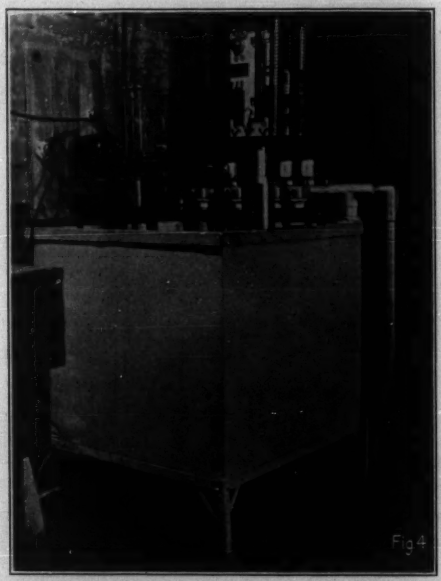
FIG. 3.



A box 6 inches by 6 inches by 33 inches contains an exposing shutter actuated by a milled head, and grooves are provided for two fluid cells by means of which light of any color can be obtained. The special acetylene burner before described is fitted on a stand having a vertical and horizontal movement by rack and pinion, so that the light itself may be placed at one metre distance from the plate surface and exactly centred. The acetylene tank, manometer, and lamphouse are also shown in the illustration. In practice two plate-holders are used—one for two plates 4¼ inches by 1 inch, the other for one plate 4¼ inches by 1½ inches; this latter holder is arranged so that two series of exposures can be impressed on the same plate. In each plate-holder only a narrow strip of the plate is exposed; the unexposed portion is used as a fog strip.

Thermostats.—The thermostat in use is a modified form of the Freas water thermostat and has proved very satisfactory.[4] The complete installation is shown in Fig. 4. The thermostat tank has a capacity of 340 litres of water and is equipped with a paddle-stirring device and mercury regulator which controls the electric heaters through a thermal relay. Hot point tubes are used as the source of heat. There are devices for maintaining

FIG. 4.

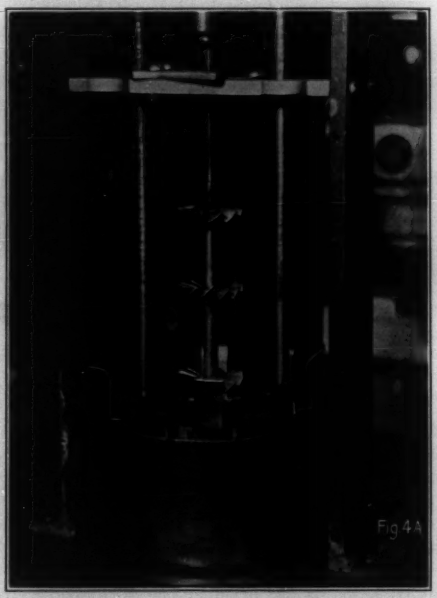


the water at constant level and for cooling the water in the tank when the room temperature is too great. A special top is fitted to the instrument with developing cups set down into the water, and the plate strips to be developed are held in small metal slides

[4] Hitchins and Gilbert, "A Water Thermostat for Maintaining Photographic Developing Solutions at Constant Temperature," *Photo. Jour. of America*, 1917, 139.

which fit around the inner periphery of the cylinder entering into the cup. Housed in an inner cylinder there is a small multiblade paddle which pulls a steady stream of developer from the bottom of the developing cup and discharges it over the top of the cylinder, distributing it evenly over the plate strips. Fig. 4*A* shows this portion of the thermostat in detail. As the various

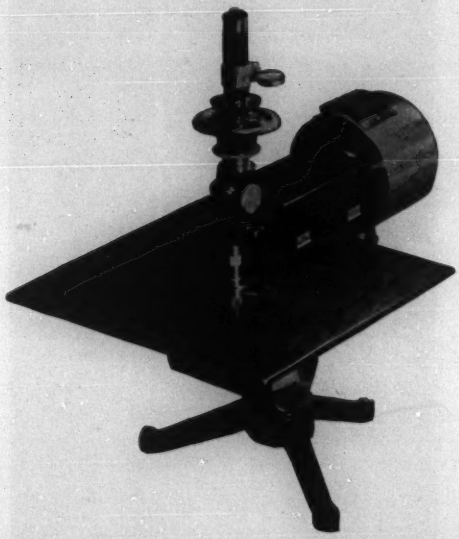
FIG. 4A.



development times are completed the plate strips in their holders can be withdrawn and placed in the fixing bath without being handled with the fingers. The accuracy of this thermostat is within one two-hundredth of a degree plus or minus, and it will run unattended day in and day out. For accurate results in sensitometry it is of vital importance that the temperature of the developer be constant.

Photometers.—A photometer as used in photographic work is an instrument for measuring the absorption of light by various media. Hurter and Driffield, in their original investigation, used the old Bunsen grease-spot photometer, a form not really suitable for photographic measurements. Polarization or spectro-photometers are now generally used in sensitometric work. The Martens polarization photometer is an excellent instrument and gives very accurate readings. In this photometer extinction is obtained

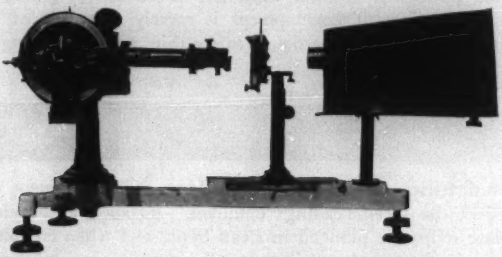
FIG. 5.



by means of a Wollaston prism. The formula for converting the readings to densities is $\log.\tan.^2\theta^1$—$\log.\tan.^2\theta$ in which θ^1 is the angle or degree of rotation with the negative density in position and θ the angle without the negative density or the zero of the instrument. This photometer is illustrated in Fig. 5. Recently a Hüfner spectro-photometer built by Adam Hilger, of London, has been used. This instrument is designed for the accurate measurement of the absorption of liquids or dyes at any

wave-length, and for the determination of the densities of photographic plates or films, for which purpose it is extremely convenient and accurate. Supposing it is desired to compare the intensities of two beams of light, one of which has undergone absorption by passage through a photographic plate, for instance: in the path of the beam which has not undergone absorption is interposed a Nicol prism which polarizes the light perpendicularly. The two beams of light are then thrown on the slit of the spectroscopic portion of the instrument, being brought into close juxtaposition with a sharp dividing line by a prism of special design. The light, after passing through the slit, undergoes collimation and is dispersed into a spectrum by a prism, and after passing through a second Nicol prism is brought to a focus and

FIG. 6.



observed by an eye-piece. Two spectra are then seen, one above the other, the one being an absorption spectrum of the substance under observation, the other spectrum being reducible by rotation of the second Nicol prism to any desired intensity. The intensity of this latter spectrum can be deduced from the rotation of the second Nicol, and thus by exact matching of any desired part of the two spectra an exceedingly accurate measurement of the amount of absorption by the material under observation can be obtained. The Hilger instrument is shown in Fig. 6. The intensity of light passing through crossed Nicols is proportional to the square of the cosine of the angle θ between them, and the formula for converting the readings to densities is as follows:

$$\text{Density} = -\log_{.10}\cos.^2\theta$$

With this instrument transparency $= \cos.^2\theta$, and opacity $= \frac{1}{\cos.^2\theta}$.

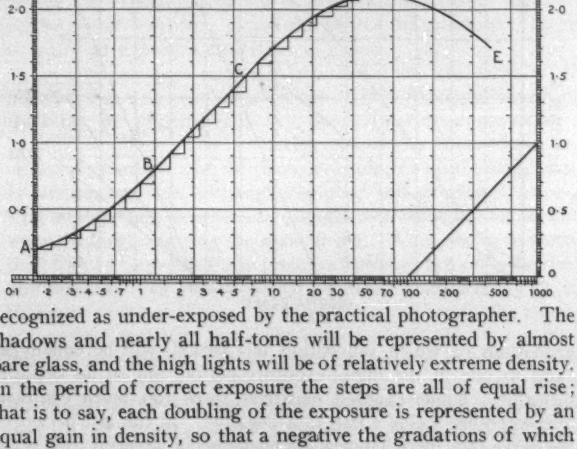
In practice the system of plate-speed measuring is carried out as follows: The acetylene light is lit; the height of the flame and gas pressure adjusted; the light should burn at least five minutes before any exposures are made, so that it may have time to settle and burn steadily. The plate-holder is loaded with two strips of the film or plate to be measured. The strips lie side by side and are exposed together in the exposing machine. Then the plate-holder is inserted in the exposing instrument, the sector wheel set revolving, the shutters of the plate-holder drawn, and exposure made by means of the flap shutter. The candle-power of the acetylene light must be known so that an exposure equivalent to 40 c. m. s. can be given, then the strips are developed for times t^1 and t^2 in such ratio that $t^2 = 2t^1$ in the thermostat at 65° F. Practically any developer may be adopted as the standard, but potassium bromide must not be added for plate-speed work. The time of development is merely a matter of convenience; if too short, the densities are thin, and if too long, the

FIG. 7.

higher densities are hard to read. Time of development does not affect the speed readings obtained. As soon as developed the plate strips are plunged in clean hypo, and when completely fixed are well washed and immersed in a 5 per cent. solution of hydrochloric acid for a few minutes to dissolve any lime salts that may be deposited in the film. The strips are then allowed to dry naturally. The negative obtained is shown in Fig. 7. One edge has been left unexposed and is called the fog strip. From this is measured the inherent fog in an emulsion, viz., the density of the gelatine, the glass, or celluloid, and any silver reduced without light action. The series of graduated densities are now measured with the photometer and the results minus fog reading plotted in the form of a curve upon a special chart. Hurter and Driffield called this the "Characteristic Plate Curve," because they found that with all plates under certain conditions of exposure the curves obtained were of the same character. The curve is always of an $\int$ shape, and if the plate has been sufficiently exposed may be divided into four regions (see Fig. 8), the concave

part *A-B* corresponding to under-exposure; the straight line period *B-C* corresponding to correct exposure; the convex part *C-D* denoting the over-exposure period; and the last period of the curve, *D-E*, corresponding to reversal. Suppose we compare this typical curve to a flight of stairs: it will be seen that in the under-exposure period the steps show a gradually increasing rise; keeping in mind that each step means growth in density, it will be seen that we have here an absolutely false relationship. In this case proportionality exists between exposure and density instead of between exposure and opacity. A negative, the gradations of which fall within this period, will have strong contrasts and be

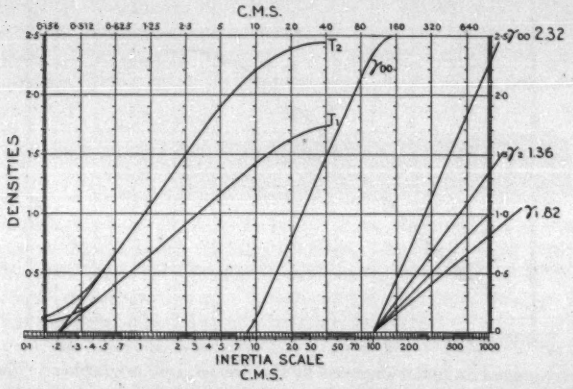
FIG. 8.



recognized as under-exposed by the practical photographer. The shadows and nearly all half-tones will be represented by almost bare glass, and the high lights will be of relatively extreme density. In the period of correct exposure the steps are all of equal rise; that is to say, each doubling of the exposure is represented by an equal gain in density, so that a negative the gradations of which fall within the period of correct exposure differs as little as possible from that which at the beginning was defined as theoretically perfect. It will be remembered that the definition of a perfect negative was that the densities of the negative should be proportionate to the logarithm of the exposures which produced them, and it is characteristic of the straight-line period of the curve

that the densities are proportionate to the logarithms of the exposures. As the result of many measurements of the densities falling within this period it has been found that the straight line portion conforms to the following simple linear equation: $D = \gamma (\log. E - \log. i)$, D being the density, γ a constant depending on time of development; E the product of intensity of light and time or the "exposure," and i a constant depending upon the speed of the plate. The over-exposure period is marked by a gradual decrease in rise in the steps, which finally become almost imperceptible. In this period the densities, instead of growing with increase of exposure, steadily decrease. A negative, the

FIG. 9.



gradations of which fall within this period, will be equally as false as one in the under-exposure period, but in an opposite direction. Under-exposed negatives show too much contrast; over-exposure yields a flat, thin negative. In the last period of the curve D-E there happens the phenomenon reversal; this is the transformation of the negative into the positive. This period is mainly of theoretical interest; such long exposures are required to produce true reversal that in ordinary photographic practice this period is negligible.

Before proceeding further it will be as well to describe the chart on which the curves are plotted. It is shown in detail in

Fig. 9. The top line of figures stand for exposures in c. m. s. The figures at the left-hand side represent densities; the bottom line of figures constitute the inertia scale which is used in determining the plate speeds. The right-hand set of ordinates are gammas and represent actual degrees of contrast in the negative. From 100 on the inertia scale there is a printed line travelling to γ 1.0, which will be explained later. To obtain the speed of a plate the straight-line portion of the curve is prolonged until it cuts the inertia scale; this point is called the inertia; then $34 \div i =$ the speed of the plate. This constant 34 holds good only when the standard light is equivalent to a standard candle. In the example shown in Fig. 9 the inertia is 0.2 and the speed is 170. The inertia is really a measure of the least exposure which will just mark the beginning of the straight line or correct exposure period. The speed of an emulsion is the inverse value: The longer the exposure required to bring a plate to the beginning of the correct exposure period the slower the emulsion. Inertia is really an exposure expressed in c. m. s.

In all plate-speed testing it is essential that two strips of the plate are exposed together; then one strip is developed for t^1 and the other for t^2; that is to say, one strip is developed twice as long as the other. The two series of densities obtained are read on the photometer, and the two curves plotted on the same chart. It will be seen that, although one strip was developed twice as long as the other, the inertiæ coincide, both straight-line portions when prolonged cutting the scale at 0.2. When we have plotted the t^1 and t^2 curves of any plate we can read not only the speed but can obtain in addition a lot of useful data relating to the character of the emulsion. We can show graphically the amount of contrast that any particular emulsion will give for a given time of development. This is done by drawing parallel with the straight-line portions of the curves t^1 and t^2, lines from 100 on the inertia scale until they cut the γ scale. Curve t^1 will then give γ^1 and t^2 will give γ^2. Supposing the times of development for t^1 and t^2 to have been 3 and 6 minutes, it will be seen that γ^1 and γ^2 represent graphically the degrees of contrast and density obtained in 3 and 6 minutes' development. Whenever the γ line of the plate coincides with the printed γ line of the chart the contrasts of the subject photographed are correctly rendered. If the reading is below 1 the contrasts of the

subject are reduced, and if above 1 are increased. Having found γ^1 and γ^2, $\gamma\infty$ is easily determined. $\gamma\infty$ is a very important factor; it measures the ultimate contrast and density obtainable with a given emulsion. $\gamma\infty$ can be determined by direct development; a strip of the plate to be tested is exposed as usual to a graduated series of light intensities and then developed for 45 minutes, the densities read and the curve plotted. A parallel to the straight-line portion of the curve is drawn from 100 on the inertia scale to the γ scale, and where it cuts is taken as $\gamma\infty$. In the example shown (Fig. 9) $\gamma\infty = 2.32$. $\gamma\infty$ can also be calculated mathematically from the figures obtained for γ^1 and γ^2; the formula is as follows:

$$\infty = \frac{\gamma 1^2}{2\gamma 1 - \gamma 2} = \frac{\cdot 82^2}{2(\cdot 82) - 1\cdot 36} = \frac{6724}{2800} = 2\cdot 40$$

For $\gamma\infty$ by direct development 2.32 was obtained, and 2.40 by calculation. In connection with the character of photographic emulsions there is another important factor—*K*, or the velocity constant; this is the speed with which a plate develops. It is arrived at in the following manner:

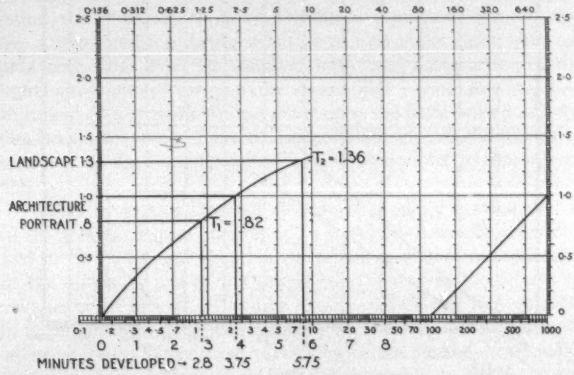
$$K = \frac{1}{t}\log_e \frac{\gamma^1}{\gamma^2 - \gamma^1} = \frac{1}{3} 2\cdot 3026 \times \log_{10} \frac{\cdot 82}{1\cdot 36 - \cdot 82}$$

$$K = \frac{1}{3} 2\cdot 3026 \times \log_{10} 1\cdot 52 = \frac{1}{3} 2\cdot 3026 \times \cdot 1818 = \frac{1}{3} \cdot 43881 = \cdot 1463$$

K depends upon the plate, the developer, and the temperature of the developer. It increases as the concentration of the developer is increased, so that in making measurements of *K* it is important that the developer be kept constant. *K* is usually higher in a slow plate than in a fast one, and decreases as the plate ages. For many purposes a plate with a high $\gamma\infty$ is very useful. It means that with under-exposure development can be forced and density piled on easily. In this case density-giving power is equivalent to speed. It has been previously stated that when the plotted γ line coincides with the printed γ line on the chart the contrasts of the subject photographed are truthfully rendered. It is well known that for different classes of work a soft, normal, or contrastive negative may be desirable. It is an easy matter to produce a negative of the degree of contrast judged to be most suitable. This is simply the control of γ. γ is entirely dependent on length of development for a given

plate, and it is easy to determine the time of development necessary to reach a given γ. It has been found that a γ or contrast of 0.80 is most suitable for portraiture where softness and modelling are important, and that for architecture a γ of 1.00 is suitable. For landscape work a γ of 1.30 has been found best. Knowing γ^1 and γ^2 for a given plate, the time of development necessary to reach a chosen γ can be shown graphically. The construction is illustrated in Fig. 10. Supposing γ^1 to be 0.82 and γ^2 1.36, use an ordinary H. & D. chart and call the base-line divisions "Minutes of Development" and the left-hand ordinates "Gammas"; then there are three points through which a curve can be

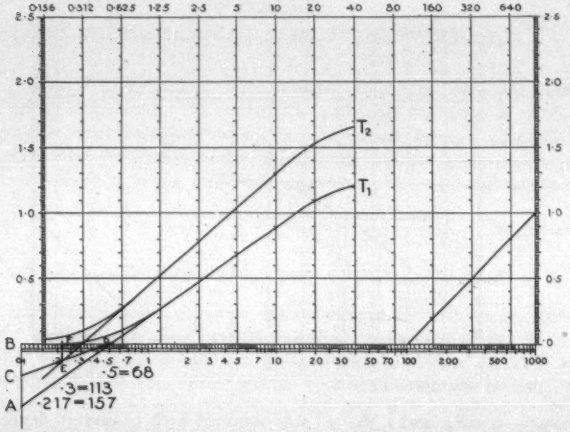
FIG. 10.



drawn—0, 0.82, and 1.36. γ^1 was obtained with 3 minutes' development and γ^2 with 6 minutes', therefore the density corresponding to γ^1 is plotted on the 3-minute line, and the density of γ^2 on the 6-minute line. To find the time of development for gammas of 0.80, 1.00, and 1.30, horizontal lines are drawn from those points on the left-hand scale, and where they cut the curve a perpendicular is dropped to the base line. In the examples shown a γ of 0.80 is obtained with 2.80 minutes' development, γ 1.00 in 3.75 minutes', and γ 1.30 in 5.75 minutes' development. There is another advantage in exposing two strips of the plate together, because when the two curves are plotted it is at once

seen if free bromide is present in the emulsion or if bromide has been added to the developer. Suppose that on plotting the two curves we find that they run more or less parallel to each other and that the inertiæ do not coincide as shown in Fig. 11: this proves that there is free bromide in the emulsion, or that bromide has been added to the developer. The presence of bromide actually lowers the speed of a plate for a given time of development, so both the inertiæ obtained are wrong, the influence of the bromide not having been overcome. The way to find the true inertia is to prolong the straight-line portion of t^1 curve below

FIG. 11.



the inertia scale, then from any point *A* draw the ordinate *A-B*. Bisect *A-B* at *C* and join *C-D*, the latter being the point where curve t^1 cuts the inertia scale. Continue the straight portion of curve t^2 until it cuts *C-D*, then from *E* erect a perpendicular *E-F* until it cuts the inertia scale, and this point 0.217 is the true inertia of the plate and the speed is 157, whereas the speed obtained from t^1 curve gave 0.5 inertia, equivalent to 68, and t^2 gave 0.3 inertia, equivalent to a speed of 113. It will be seen that this construction is merely a mathematical anticipation of the true speed of the emulsion that will be obtained if develop-

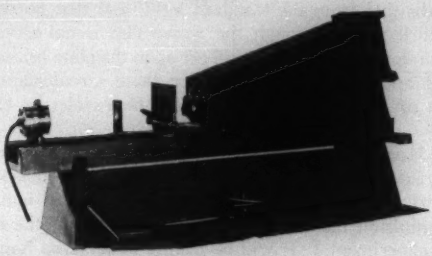
ment is continued sufficiently long to overcome the restraining action of the bromide.

Another very important property of a plate is its latitude. This can be judged fairly well from a straight-line portion of the plate curve. Supposing the straight-line portion extends from 1.25 c. m. s. to 20 c. m. s., then any exposure ranging from 1 to 16 would be in the period of correct exposure. Latitude is really the measure of the opacity of the unexposed plate to blue-violet light and can be determined more accurately as follows: A plate of known speed is exposed behind the plate the latitude of which is to be measured. For instance, suppose a plate with a speed of 150 is exposed behind an Ansco film, and, when the densities are read and plotted, gives a speed of 100, then 150 minus 100 = 50, which is the latitude of the Ansco film, because the Ansco emulsion, being sensitive to blue-violet light, cuts out or absorbs this from the standard light, and that portion of the light which passes through the Ansco film is not absorbed and so cannot do any work but it will act upon the plate behind and the densities and speed obtained under these circumstances are a measure of the non-absorption of the blue-violet by the Ansco film.

The Hurter and Driffield system, if properly carried out, is of the greatest help in maintaining a standard of emulsion quality, and in its wider and deeper applications is almost indispensable to the emulsion maker for graphically recording the effects of various experiments. It will be readily understood how changes in an emulsion during manufacture will be shown in the curves when plotted. What these variations in the plotted curve mean to the emulsion maker would entail a thorough discussion of the theory and practice of emulsion making, which is not possible in an article of this nature. In the various branches of photographic work it is necessary to use emulsions of different character. In process and copying work a slow plate having good latitude and a high $\gamma\infty$ is desirable. It should develop quickly and be capable of giving great density and contrast, and it is important that the inherent fog of the emulsion should be low. An emulsion intended for the general run of hand camera work where most of the results are underexposed should have a high speed, develop rather slowly, and have a reserve density and contrast-giving power. The under-exposure period should be well

defined, and it is desirable that the emulsion be yellow-green sensitive, or, in other words, orthochromatic. An emulsion intended for portraiture should have a very high speed around about 250 H. & D. It should develop slowly, and the $\gamma\infty$ should not be higher than 2.00. It should have good latitude and a well-defined under-exposure period. In the modern practice of portraiture the tendency is to use a rapid orthochromatic or panchromatic emulsion. The inherent or chemical fog of any emulsion must be kept as low as possible. This is one of the problems of emulsion making. The inherent fog of any emulsion should not be higher than 0.20, even when the plate is developed to $\gamma\infty$. The speed readings obtained can be used directly as a basis for the calculation of exposure, because, providing two plates of different kinds are impressed with the same series

FIG. 12.



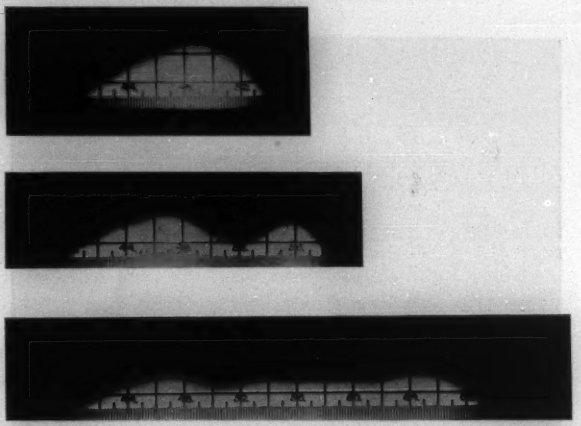
of known exposures by the same light-source, their speeds are inversely proportional to their respective inertiæ; for instance, if strips of plates A and B are impressed with the same series of graduated exposures by the sector wheel, and the inertia of A is found to be 0.2, while the inertia of $B = 0.4$, then the speed of A is twice that of B. If the speed of B is 85 H. & D., then the speed of $A = \frac{85 \times .4}{.2} = 170$ H. & D.

There are one or two other applications of the H. & D. system that are of use in practical photography. For instance, if we have to test a set of developers for their density-giving or reducing properties, a series of strips of the same emulsion are exposed and these strips developed in the different developers or combinations of them. When the strips have been read their

curves will show graphically the performance of the various developing agents. For estimating the action of the various intensifiers and reducers a number of strips are exposed and their curves plotted, then if any of the plate strips are submitted to the action of an intensifier or reducer the difference between the curve obtained after treatment and the first curve is an indication of the action to which the plate has been subjected.

Apart from the determination of the speed, fog, gamma infinity, and velocity constant of emulsions, there is another very

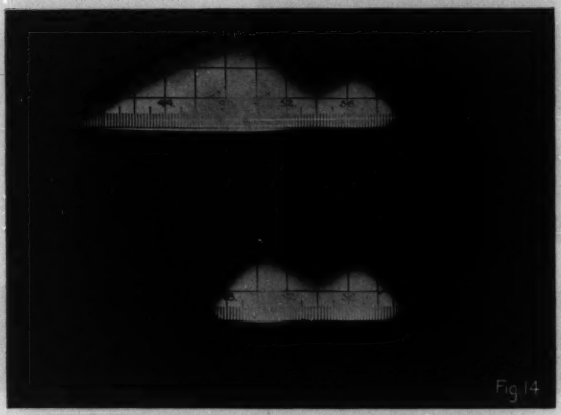
FIG. 13.



important factor which must be considered: this is color sensitiveness. To determine this, a Hilger diffraction grating spectrograph is used. This instrument is designed so as to project and bring to a focus in the image plane a diffraction spectrum much as any image is brought to a focus on an ordinary camera. The complete instrument is shown in Fig. 12. The plate-holder is 3¼ by 4¼ inches, and has fitted into it an accurately engraved wave-length scale. The plate to be tested is exposed behind the wave-length scale to the action of the spectrum. The spectroscopic slit has in front of it a black glass wedge that produces a

gradient of exposure across the width of the spectrum so that we obtain a negative that shows graphically the color-sensitiveness curve of the emulsion. This automatic curve plotting is due to the wedge. If a plate is very sensitive to a certain color, that color will stand more damping down by the wedge before its power to impress the plate is lost than will a color to which the plate is not so sensitive, and so the maximum or peak of the curve represents the wave-length to which the plate is most sensitive. The results obtained are illustrated in Fig. 13; the top curve is the usual one given by non-color sensitive emulsions.

FIG. 14.



Its maximum is at wave-length 4900 in the blue, and it is quite insensitive to yellow. The second curve is characteristic of an orthochromatic or color-sensitive emulsion. A maximum still exists in the blue, but in addition there is a secondary maximum at 5600 in the yellow. This additional color-sensitiveness is obtained by adding a dye—erythrosine—to the emulsion during manufacture. The presence of the dye gives to the emulsion the power of absorbing yellow light instead of passing it, and the light so trapped is used in forming a developable image. The third curve is typical of a panchromatic emulsion.

There is an almost equal sensitiveness throughout the spectrum. In panchromatising an emulsion two dyes are usually used—pinachrome and pinacyanol. It is not usual to incorporate these dyes with the emulsion during manufacture, but the finished plates are bathed in a solution of the dyes. The first two curves show the importance of orthochromatism. A non-color sensitive plate will render even dark blue as white and light yellow as black, in absolute contradiction to the visual effect. It cannot well be otherwise, since the greatest sensitiveness of an ordinary plate is in the blue, and there is no record made of anything yellow, so yellow must be rendered as black and blue as white

FIG. 15.

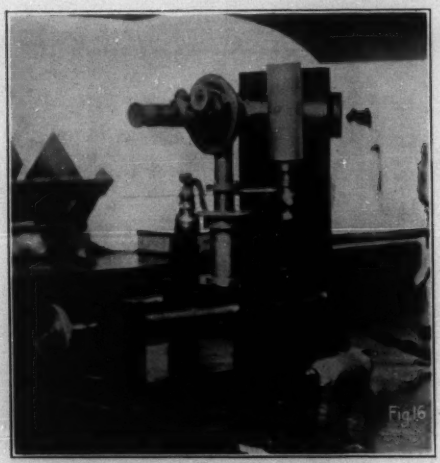
in the final print. An orthochromatic emulsion giving a curve like No. 2, having a secondary maximum in the yellow, will give a better rendering of color luminosity, but not a really true rendering, because the blue sensitiveness is still predominant. How to obtain true color correction by the use of a yellow screen is shown in Fig. 14. The first curve is characteristic of an unscreened orthochromatic emulsion with maximum sensitiveness in the blue. The second curve shows the effect of exposing through a screen having a multiplying factor of five. The action of the blue has been curtailed, and colors will now be rendered in practically their correct values. The maxima have been shifted, so that blue, blue-green, and yellow will be rendered as they appear visually.

All of the foregoing discussion has been in connection with negative emulsions, but recently a modification of the plate-test-

ing system has been applied to the determination of the character of developing-out paper emulsions.

For this work a sector wheel is also used for producing a known series of exposures; the form of the wheel is shown in Fig. 15. There are 16 sectors increasing in value as powers of the square root of 2. Geometric step-up in exposure is not practical for paper emulsions; such steps are too widely separated to reveal the delicate gradation scale. The exposing instrument used in this work is practically the same as that for negative

FIG. 16.

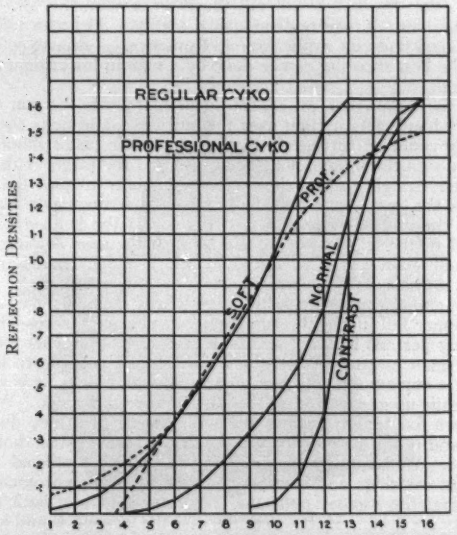


emulsions, but in order to keep exposure within reasonable limits a 15-candle-power electric glow lamp is used, controlled by a potentiometer. The paper strips are developed at standard temperature, and after drying are read in a specially designed photometer. When reading paper deposits we are, of course, dealing with differences in reflecting power, which vary according to the amount of silver reduced. In devising a photometer for reading reflection densities precautions must be taken to avoid specular reflection or polarization of light at the surface of the

paper. The photometer in use for this purpose is illustrated in Fig. 16. The strip of graduated densities is illuminated with 45-degree light, and the tube of the instrument is at right angles to the paper surface. The photometer is a modification of the Martens instrument.

In Fig. 17 the curves obtained with the various grades of Cyko paper are shown. The curve given by Contrast Cyko is characteristic of this emulsion and shows the short scale and steep

FIG. 17.



rise of a paper of this type. Normal Cyko has a longer scale and less steep rises in density. Soft Cyko and Professional Cyko give curves that are characteristic of their performance.

The paper-measuring system has been in use only a short while for determining and maintaining a standard of quality in developing-out paper emulsions. There is, however, every indication that it will prove as useful as the system of plate-speed measurements has in the control of negative emulsions.

BINGHAMTON, N. Y., May, 1917.

Common Misconception on Pistol Shooting. A. P. LANE. (*New York Sunday American*, 1914. Issued by Colt's Patent Fire Arms Manufacturing Company, Hartford, Conn.)—Pistol shooting—and, for that matter, all kinds of shooting—is the subject of more misconception on the part of the public or layman than any other sport extant. It is popularly supposed that a pistol in the pocket or within easy reach is a protection, quite without regard to the possessor's ability to use the weapon properly. As the average man uses a pistol it is not effective more than ten feet from the mark. At that distance, if the arm wavers a half inch, as is quite likely, because of the sudden jerk on the trigger—a fault characteristic of the novice—that the bullet will not touch an assailant at all. Skill in shooting does not require phenomenal ability. Any man can become a fair marksman by application and practice. Training is unnecessary; the best shooting can be done by a man in his ordinary normal condition.

To the uninitiated, an expert pistol shot holds the gun out with a steady hand, gets it right over the bull's-eye, and pulls the trigger. Nothing could be further from the fact. The pistol shooter cocks the gun with the thumb, holds it out toward the target with his arm extended straight, takes aim, begins gradually to pull the trigger, watches the gun weave back and forth across the mark, and, when it is in the middle of one of its trips across the bull's-eye, finishes the pull of the trigger. There is no such thing as holding a pistol immovably over a bull's-eye and shooting—that is a human impossibility. The arm is bound to sway to and fro, even if ever so slightly, and the only way to hit the centre of the bull's-eye is to have the hammer fall just as the gun happens to be going across the mark.

Many persons believe, because a pistol kicks up when fired, that a marksman estimates how much the weapon is going to kick and aims at a correspondingly low point. The gun kicks, it is true, but that entails no guesswork on the part of the marksman. When the sights are fixed, allowance is made for the upward kick due to the recoil, and if the sighting of the shooter is accurate the shot will be accurate. With automatics, in which the recoil is utilized to expel the spent cartridge and insert a new one, it is not uncommonly believed that the shooter pulls the trigger and holds it back until all the shots are fired. If this were the case the weapon would kick up a little with every shot and the shooter would shoot himself in the face in the fraction of a second. These pistols shoot easily with a very slight trigger pull, but the trigger must be released and pulled for each shot.

MODERN DYNAMO ELECTRIC MACHINERY.*

BY

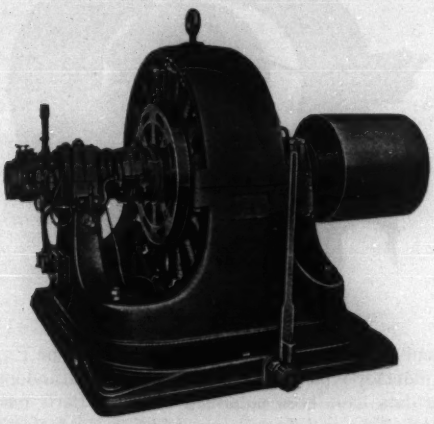
ALEXANDER GRAY, M.Sc.,

Professor of Electrical Engineering, Cornell University, Ithaca, N. Y.

ALTERNATING-CURRENT GENERATORS.

We have already seen that direct-current machinery had become somewhat standardized by 1890, and that the Hobart machine, described on page 22, has design constants and a type of mechanical construction which do not differ much from those of

FIG. 32.



Belt-driven single-phase alternator, 90 k.w., 16,000 alternations.

similar machines of recent date, but at that time, 27 years ago, there was no one type of alternator that was considered superior to all others.

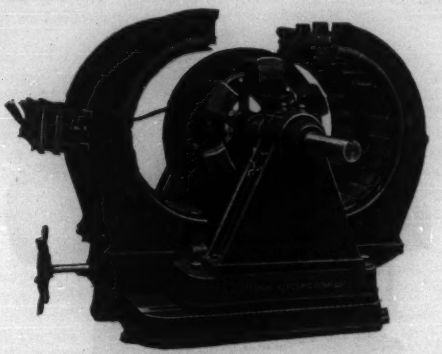
The first Niagara machines, shown in Fig. 3, had an external rotating field system, this type of construction being considered necessary to give the large flywheel effect required to maintain

* Continued from page 48, July issue.

the speed approximately constant with changing load. Rotating armature machines, such as that shown in Fig. 32, were still listed in 1903, and inductor alternators of the type shown in Fig. 33 were on the market as late as 1907, but the advantages of the present type of internal rotating field construction were such that by 1900 most of the other types had been discarded, so that Guilbert, in describing the alternators that had been on exhibit at the Paris Exposition in 1900, states as follows:

"One of the most striking features was the triumph of the three-phase system even for lighting; of equal interest was the

FIG. 33.



Inductor alternator with vertically split armature.

fact, as had been foreseen before the opening of the Exposition, that the inductor type of alternator was being abandoned."

Many data have been published on these Paris machines.[14] From these data, and from some additional information published by Rothert,[15] the seven machines in Table III have been selected as typical alternators of 1900, and these we shall use as a starting point in our study of modern machines. Let us

[14] *L'Éclairge Électrique*, vol. 29, p. 276, November 23, 1901; *Electrical World*, vol. 37, pp. 113, 154, 194, 231, 274, 302, 352, 398, January to March, 1901.

[15] *L'Éclairage Électrique*, vol. 29, p. 307, November 30, 1901. See also "Engineering Evolution of Electrical Apparatus," Lamme, *Electric Journal*, vol. 11, p. 73.

first, however, take up the various limitations in the design of polyphase alternators.

TABLE III.

Kv.a	215	800	800	860	1000	1330	1400
Volts	220	2200	2200	2400	5000	5500	3000
Ampères	563	210	210	207	115	140	270
Phases	3	3	3	3	3	3	3
Frequency	32	42.5	50	50	50	25	50
R.p.m.	120	80	79	94	94	75	72
Poles	32	64	76	64	64	40	84
Internal diameter of stator in inches	106	236	236	197	230	214	252
Frame length in inches	10	10	10.7	11	11.8	17	10
m. Pole pitch in inches	10.4	11.6	9.8	9.7	11.35	16.8	9.4
n. Air-gap clearance in inches	.107	.312	.275	.275	.312	.43	.235
Ratio m/n	52.5	37	35.5	35	36	39	40
Slots per pole	3	6	6	3	6	6	6
Size of slot in inches	1.85 dia.	.87×1.4	.6×1.15	1.7×2.5	1.1 dia.	1×2.7	.83×2.2
Conductors per slot	9	6	5	7	6	9	6
Connection	YYYY	delta	YY	Y	Y	Y	delta
Tooth/slot	—	1.24	1.72	.9	—	1.8	1.0
Maximum tooth density at no load in lines per square inch	104,000	110,000	65,000	115,000	104,000	77,000	100,000
Core density at no load	29,000	30,000	21,000	30,000	18,000	54,000	26,000
Pole density at no load	118,000	120,000	111,000	118,000	109,000	90,000	114,000
a. Ampère conductors per inch of periphery	365	375	320	450	370	450	570
b. Circular mils per ampère,	740	430	450	620	725	1060	480
Ratio a/b	.49	.87	.71	.72	.51	.42	1.18
Peripheral velocity of rotor in feet per minute	3320	4950	4900	4850	5650	4200	4750
c. Ampère turns per pole at no load	5385	7600	4600	6950	5175	8050	6675
d. Armature ampère turns per pole	1920	2200	1600	2200	2100	3800	2750
Ratio c/d	2.8	3.45	2.87	3 15	2.46	2.12	2.42
Pole enclosure	.57	.5	.8	.61	.66	.65	.64
Output factor × 100	1.64	1.82	2.12	2.15	1.72	2.3	3 1

$$\text{Volts per phase} = 2.22 \times \text{conductors per ph.} \times \phi \times f \times 10^{-8}$$

$$\text{Tooth area per pole} = \text{minimum tooth} \times \text{slots per pole} \times \text{net iron in frame length.} \times \psi$$

$$\text{Pole density} = \text{gap flux} \times \text{leakage factor/pole area}$$

$$\text{Ampère conductors per inch of periphery} = \frac{\text{current per conductor} \times \text{conductors per phase} \times \text{phase}_s}{\pi \times \text{stator internal diameter}}$$

$$\text{Ampère turns per pole at no load} = op. \text{ Fig. 38.}$$

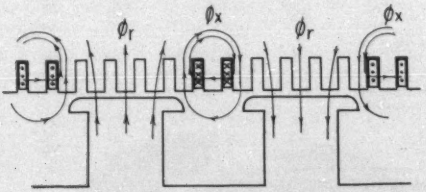
$$\text{Armature ampère turns per pole} = \frac{\text{current per conductor} \times \text{conductors per pole}}{2}$$

$$\text{Output factor} = \frac{\text{volt ampères}}{rpm \times D^2 L}$$

PERFORMANCE CHARACTERISTICS.—Fig. 34 is a section of a three-phase alternator showing the conductors of only one phase. When this machine is supplying current, these conductors are encircled by the lines of force of the alternating magnetic fluxes

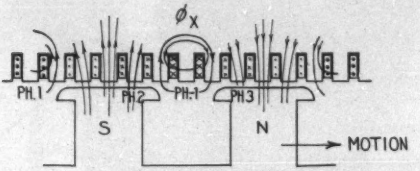
ϕ_x and ϕ_r. The former, often called the armature leakage flux, generates a voltage of self-induction in the conductors which is proportional to the current and is equal to IX where X, called the leakage reactance, is constant, since the flux ϕ_x is proportional to the current which produces it, the reluctance of the

FIG. 34.



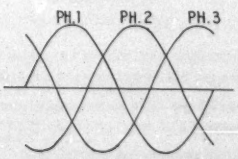
Armature fluxes produced by one phase of a three-phase alternator.

FIG. 35.



Armature field of a three-phase alternator when the current lags 90 degrees.

FIG. 35A.



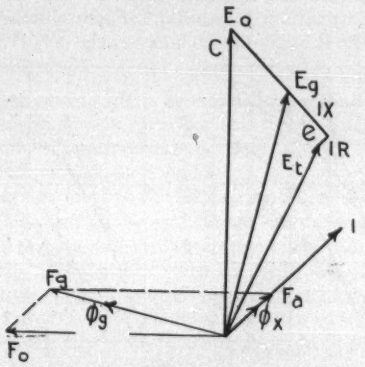
Currents in three phases.

leakage path being practically all in the air part of the path. The magnetic flux ϕ_r enters the poles and so modifies the main field.

Fig. 35 shows a section through the same three-phase machine and shows the current distribution in the conductors when the power factor of the load is zero and the current lags 90 degrees

behind the terminal voltage. Under these conditions the current is a maximum in the conductors that are between the poles, because in these conductors no electromotive force is being generated. The three fluxes ϕ_r, produced by the three phases, combine to give a gliding field exactly as in an induction motor, which field is proportional to the current flowing and moves at synchronous speed in the same direction as the rotating poles. The phase relation between this armature field and that produced by the poles depends on the power factor of the load and, as shown in Fig. 35, directly opposes the main field at zero power factor.

FIG. 36.



Vector diagram per phase of a polyphase alternator.

These effects of armature reaction can best be indicated by a vector diagram, as shown in Fig. 36.

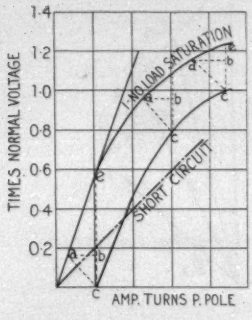
The no-load m.m.f. F_o produces an alternating flux in the winding of each phase, and the voltage E_o generated in each phase lags F_o by 90 degrees.

The m.m.f. of the armature produces a synchronous gliding field of constant magnitude and causes an alternating flux to thread the windings of each phase. It may be seen from Fig. 35 that the armature flux threading phase 1 is a maximum when the current in that phase has its maximum value; thus in Fig. 36 we have:

F_0 is the no load m.m.f.
E_0 is the voltage per phase due to F_0.
I is the current per phase.
F_a is the m.m.f. of armature reaction which, as pointed out in the last paragraph, is in phase with I.
F_g is the resultant m.m.f. due to field and armature.
ϕ_g is the resulting synchronous flux.
E_g is the voltage per phase due to ϕ_g.
ϕ_x is the armature leakage flux per phase.
IX is the leakage reactance drop.
E_t, the terminal voltage per phase, $= E_g - IX - IR$ taken as vectors.

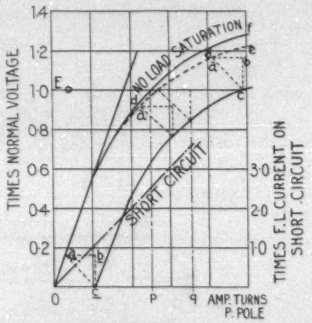
The voltage drop *ce* due to the combined effect of leakage reactance drop and drop due to armature reaction is generally called the synchronous reactance drop.

FIG. 37.



Characteristic curves of an alternator.

FIG. 38.



Test curves of a 150-kw., 600 r.p.m., three-phase alternator.

In the particular case when the power factor is zero and the current lags the terminal voltage by 90 degrees, the leakage reactance drop is subtracted directly from the generated voltage, and the magnetomotive force of armature reaction is subtracted directly from the exciting m.m.f. The voltage drop due to armature reaction, however, decreases as the poles become saturated, because the same m.m.f. produces a gradually decreasing reduction in the flux. These two effects are well shown in Fig. 37, where curve 1 is the no-load saturation, *ab* is the m.m.f. to overcome the demagnetizing effect of armature reaction, and *be*

is the voltage drop due to this effect, *bc* is the leakage reactance drop, and *c* is a point on the full-load saturation curve at zero power factor.

It is found in practice, however, that the two curves are not parallel to one another as shown, but gradually separate as in Fig. 38, which gives test data on an actual machine. The additional voltage drop is due to the pole leakage. The m.m.f. required to generate a voltage E_0 on no load is *op*, Fig. 38, but, when the alternator is loaded and the power factor is zero, the m.m.f. for the same generated voltage is *oq;* the flux crossing the air-gap is unchanged, but the leakage flux from pole to pole is increased in the ratio *oq*/*op*, and, under these conditions, an increased excitation is required because of the higher densities in the pole core. The relative amounts of these three effects can be shown as follows:

The distance *ab*, Fig. 38, is determined from the formula:

Demagnetizing ampère turns per pole = $0.35\ Z\ I_c/p$.

where Z/p is the total conductors per pole,

I_c is the current per conductor,

and the distance *bc* must be the leakage reactance drop; this can be checked approximately by calculation. If the triangle *abc* be now placed so that the full-load saturation curve found by actual test is the locus of the point *c*, then the locus of point *a* is what designers call the no-load saturation curve figured with the full-load leakage factor, and the excitation *ad* is the additional excitation for the poles over that required at no-load for the same air-gap flux.

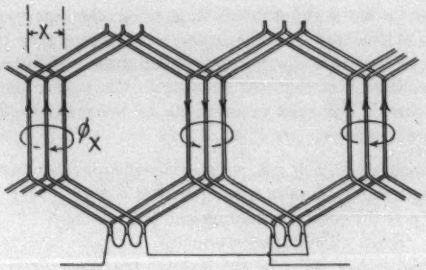
LIMITATIONS IN DESIGN.—If it is desired to have good regulation, particularly with low power factor loads, it is necessary to keep the synchronous reactance drop *fc*, Fig. 38, small compared with the normal voltage. To accomplish this result:

1. Keep the leakage factor small and the pole density below saturation.
2. Keep the leakage reactance small: this, as shown in Fig. 39, means limiting the number of ampère conductors in the phase belt *x* or, what is equivalent, limiting the number of ampère conductors per inch of armature periphery.
3. Keep the demagnetizing ampère turns per pole a small

fraction of the exciting ampère turns per pole and saturate the magnetic circuit so as to make the voltage drop *be* small.

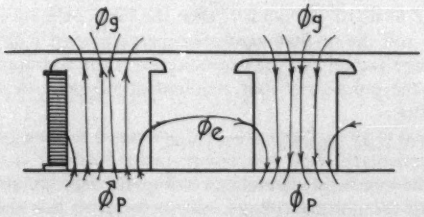
One may well ask why the output of this particular machine is limited to 150 kilowatts. Why would it not be possible to increase the main excitation and thereby allow a larger current to be carried by the armature without any sacrifice of regulation?

FIG. 39.



Winding of one phase of a three-phase alternator, showing the leakage flux.

FIG. 40.

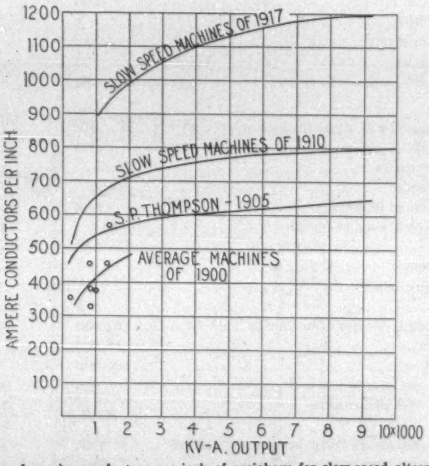


The main field and the pole leakage field of an alternator.

Fig. 40 shows part of a machine to scale. Of the flux ϕ_p which enters the pole, the leakage flux ϕ_l at no load is 20 per cent., and the useful gap flux ϕ_g is 80 per cent., under which conditions the pole density at the root is 100,000 lines per square inch, and the tooth density 95,000, while the length of the pole is just sufficient to give the necessary radiating surface to the field coils.

If, then, the field excitation is increased 50 per cent., the pole length will increase in the same ratio to dissipate the additional heat, the air-gap will be increased to use up the increased m.m.f., since ϕ_g, limited by the tooth density, remains constant, but the area as well as the m.m.f. of the leakage path will be increased, so that the leakage will become $(1.5)^2$, or 2.25 times the original value, and the flux density at the root of the pole will be excessive.

FIG. 41.



Values of ampère conductors per inch of periphery for slow-speed alternators.

For a satisfactory machine, therefore, all of the dimensions in Fig. 40 must increase as the ampère turns per pole are increased, so that one constant in design is the ratio ampère turns per pole/pole pitch, the value of which ratio can be increased either by raising the permissible temperature rise of the field coils or by improving the ventilation. It is of interest to note, however, that, in order to obtain a certain desired voltage regulation, the armature ampère turns per pole are made a definite fraction of the main excitation, so that the constant used by the designer is rather the ratio of armature ampère turns per pole/

pole pitch, of which the ampère conductors per inch of armature periphery are a definite measure. This constant, therefore, which we found to be of great importance in direct-current design, is of equal importance in the design of alternators, but, since its value depends on so many factors, the writer who gives a table of values is subject to criticism. Let us, however, examine a few machines and see what values are found in practice.

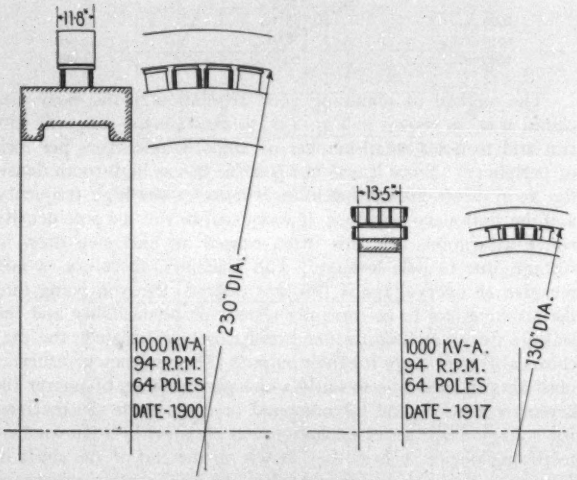
TABLE IV.

Kv.a.	1000	
Phases	3	
Frequency	50	
R.p.m.	94	
Poles	64	
Date	1900	1917
Internal diameter of stator in inches	230	130
Frame length in inches	11.8	13.5
Centre vent ducts	None	3 of ½ inch
End vent ducts	None	2 of 1 inch
m. Pole pitch in inches	11.35	6.4
n. Air-gap clearance in inches	5/16	3/16
Ratio *m*/*n*	36	34
Slots per pole	6	6
Size of slot in inches	1.1 dia.	.5×2.75
Tooth slot	0.8	1.12
Maximum tooth density at no load in lines per sq. in.	104,000	100,000
Core density	18,000	50,000
Pole density	109,000	95,000
a. Ampère conductors per inch	370	900
b. Circular mils per ampère	725	750
Ratio *a*/*b*	.51	1.2
Peripheral velocity of rotor in feet per minute	5700	3200
c. Ampère turns per pole at no load	4500 by test	3700
d. Armature ampère turns per pole	2100	2880
Ratio *c*/*d*	2.15	1.28
Pole enclosure	0.66	0.7
Output factor	0.0172	0.047
Guaranteed temperature rise	40° C.	50° C.

Table III gives data on several of the machines that were exhibited at the Paris Exposition; the 1400-kv.a. machine is of special interest because Rothert claims that it is so much superior to other machines of that time. The values of ampère conductors per inch found in these machines are plotted in Fig. 41, and on the same diagram are plotted figures given by S. P.

Thompson in 1905; these indicate the improvement in ventilation in five years. The figures of 1910 are higher because operating engineers were willing to accept poorer regulation in order to get a cheaper machine, while the enormous increase in the last seven years is due partly to the fact that the larger machines are now rated at 50° C. rise with no overload guarantee, but more particularly to the fact that regulation has been thrown to the winds and the voltage maintained at all loads and power factors by voltage regulators such as these first invented by Tirrell.

FIG. 42.



Comparison between a machine built in 1900 and one built in 1917 for the same output.

Perhaps the best conception of the progress made in design, and of the entire change in performance characteristics, may be obtained from Table IV, which gives comparative data on the 1000-kilovolt-ampère machine exhibited at the Paris Exposition and on a unit as designed to-day for the same output. The two machines are drawn to scale in Fig. 42, and the performance characteristics are given in Fig. 43. With an excitation neces-

sary to give normal voltage on no-load, the current on short-circuit is 2.75 times full-load current in the early machine and is only 1.5 times full-load current in the more recent design. In the case of alternators of large output, when the air-gap clearance is not limited partly by mechanical clearance, the short-circuit current with normal no-load excitation does not greatly exceed the full-load value.

The regulation guarantees expected at various times have been:

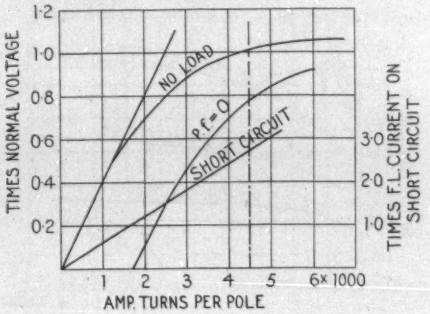
Date	Regulation at 100 per cent. power factor	Regulation at 80 per cent. power factor
	Per cent.	Per cent.
1900	5	15
1910	8	20
1917	20	40

The method of obtaining good regulation in the early machines was, as shown in Fig. 43*a*, to saturate the magnetic circuit and to use a small number of ampère conductors per inch of periphery. Since it was not possible to use high tooth densities as in direct-current machines because of the high frequency and the stationary armature, it was usual to run the pole density above saturation, and this often caused an excessive drop in voltage, due to pole leakage. The machines, therefore, would not give an overvoltage if this was desired; the iron going into the machine had to be carefully tested for permeability and the leakage fluxes and saturation curve closely calculated; the machines also were large for their output. The tendency in America until almost 1900 was to build a cheaper machine, of poorer inherent regulation, and to compound or compensate the machine for voltage drop; series excitation was obtained by some kind of rectifying device such as that shown on the end of the shaft in Fig. 32. This scheme worked well on the small single-phase units used for lighting service, because the power factor was approximately constant, but it gradually lost favor as the polyphase system came into general use.

The extent to which alternators have been gradually rated up is well indicated by the curves of output constant given in Fig. 44. It is of interest to note from these curves that, contrary to general opinion, the core dimensions of an alternator are greater than those of a direct-current machine of the same output. This

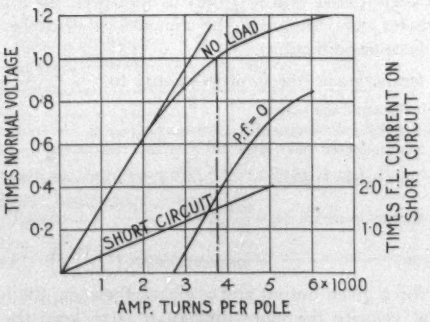
is due principally to the fact that, whereas in direct-current machines tooth densities of 150,000 lines per square inch are not exceptional, values of 100,000 lines per square inch cannot safely be exceeded in 60-cycle alternators, because the loss at that frequency is large, while the ventilation of a stationary core is not nearly so effective as is that of a rotating armature.

FIG. 43A



Performance characteristics of the machine built in 1900.

FIG. 43B.

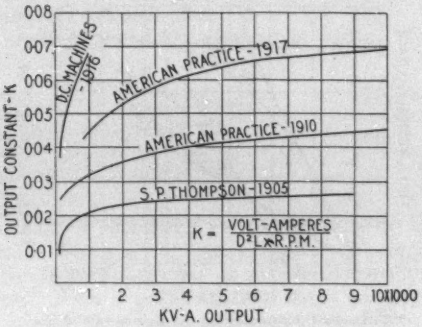


Performance characteristics of the machine built in 1917.

VENTILATION.—Many of the early alternators were so large for their output that no special provision was necessary in order

to keep the temperature rise down to a safe value. The machine shown in Fig. 42, for example, does not even have vent ducts in the stator. Even in the case of modern machines, the slow-speed alternator does not require that any special precautions be

FIG. 44.



Output constants of slow-speed alternators.

taken to keep it cool, and it is only as the speed for a given output increases, and therefore the dimensions decrease, that the problem becomes difficult.

The temperature rise is proportional to $\frac{\text{watts loss}}{\pi DL(a+bV)}$ where

$\pi D L$ is the armature surface

V is the peripheral velocity of the armature

a and b are radiation and convection constants respectively.

$$\text{The output in } Kv.\ a. = \frac{D^2L \times rpm}{K} = (DLV) \times \text{a constant},$$

$$\text{therefore temperature rise} = \frac{\text{watts loss}}{(a+bV)} \times \frac{V}{\text{output}} \times \text{a constant}$$

$$= (\text{per cent. loss}) \times \left(\frac{V}{a+bV}\right)$$

so that, for a given output and a given efficiency, the higher the peripheral velocity the more difficult it is to keep the machine cool. But note further that

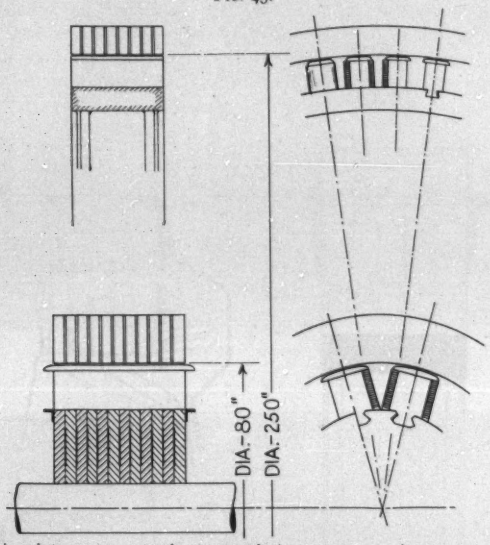
$$V = \frac{\pi D}{12} \times \text{rpm}$$

$$= \frac{\pi D}{12} \times \frac{120f}{p}$$

$$= 10 \times \text{pole pitch} \times \text{frequency}$$

so that, for a given output and given frequency, the greater the pole pitch the more difficult it becomes to keep the machine cool. This is shown in rather a striking way if we compare two water-

FIG. 45.



Comparison between two 10,000-kv.a. water-wheel generators, one of 100 r.p.m. and the other of 600 r.p.m.

wheel generators, one to operate on a high head and the other on a low head: compare, for example,

Kv.a.	10,000	10,000
Rpm.	600	100
Poles	12	72

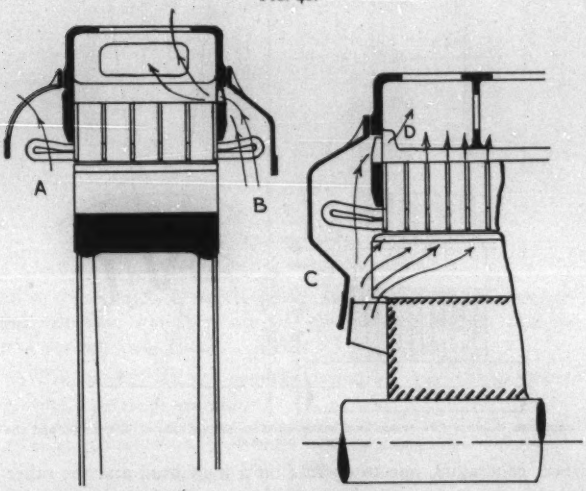
Probable dimensions are:

Internal diameter of stator in inches	80	250
Frame length in inches	37	26
Pole pitch in inches	21	10.9
Peripheral velocity of rotor in feet per minute	12,500	6500
Peripheral velocity at run-away speed	22,500	11,700

These machines are drawn to scale in Fig. 45, and it can now be readily seen why the high-speed machine is so difficult to ventilate: it has not the radiating surface of the slow-speed machine.

In slow-speed machines the air is stirred up around the stator by the rotor itself, no fan blades being necessary. The whole construction is open, as shown in Fig. 47, and also in diagram A, Fig. 46. With this type of ventilation the air is

FIG. 46.

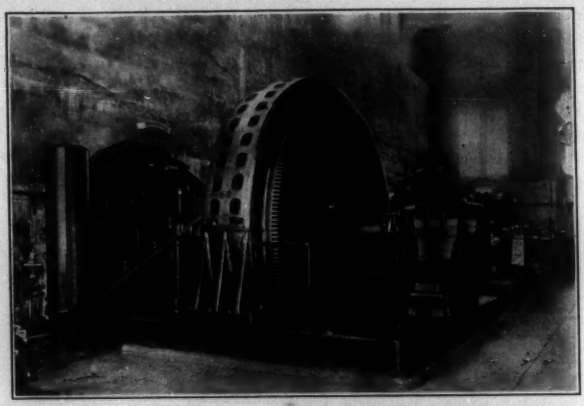


Different methods of ventilating alternators.

not always directed where desired, and the air streams are rather unstable, so that one side of the machine is often cooled better than is the other. With moderate-speed machines it becomes necessary to properly direct the air, which result is generally accomplished by the addition of fans to the rotor, while the housings are often made solid, as shown in Fig. 48, and also in diagram B, Fig. 46, so as to deflect the air over the back of the stator windings and core.

In the case of high-speed water-wheel units, under which

FIG. 47.



Generator with open end bells.

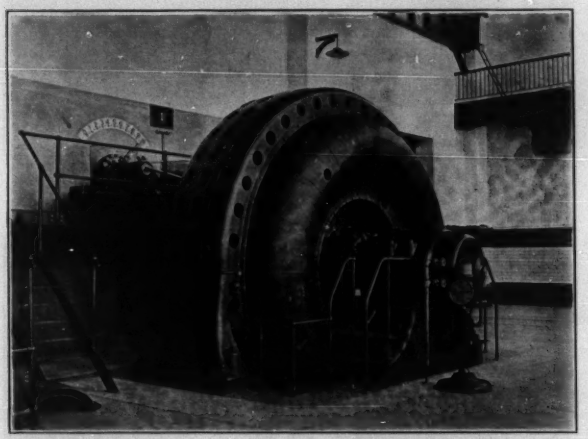
FIG. 48.

Generator with solid end bells.

class would come the 600-r.p.m. machine in Fig. 45, the frame is generally long in order to keep the peripheral velocity down to a safe value, and in such cases it is necessary to create an air-pressure in the end bells to force the air between the poles and out through the vent ducts in the centre of the stator core, as shown in diagram C, Fig. 46, and also in Fig. 49; comparatively small openings are left at *D*, Fig. 46, to ventilate the end bells.

MECHANICAL CONSTRUCTION.—One feature of interest is the growing popularity of the vertical shaft or umbrella type of

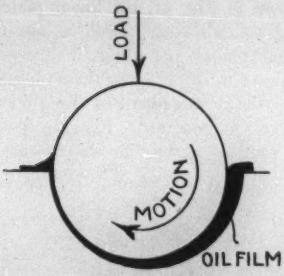
FIG. 49.



Generator with enclosing end bells and forced ventilation.

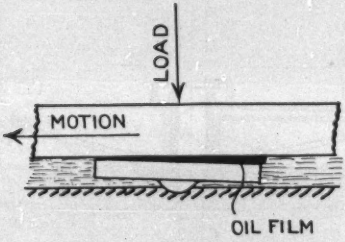
water-wheel generator. This has been due partly to improvements in the design of this type of water-wheel, but also in large measure to the development of a reliable thrust bearing. The Kingsbury bearing makes use of that feature of the horizontal shaft bearing on which its ability to carry large pressures depends; namely, that, as shown in Fig. 50, the oil is drawn into the high-pressure space as a wedge, by the rotation of the shaft itself. The stationary thrust plate of this type of bearing is made of a number of segments, as shown in Fig. 52, these seg-

FIG. 50.



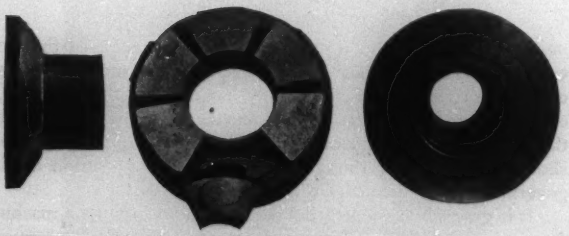
Oil film in the bearing of a horizontal shaft.

FIG. 51.



Oil film in the Kingsbury thrust bearing.

FIG. 52.

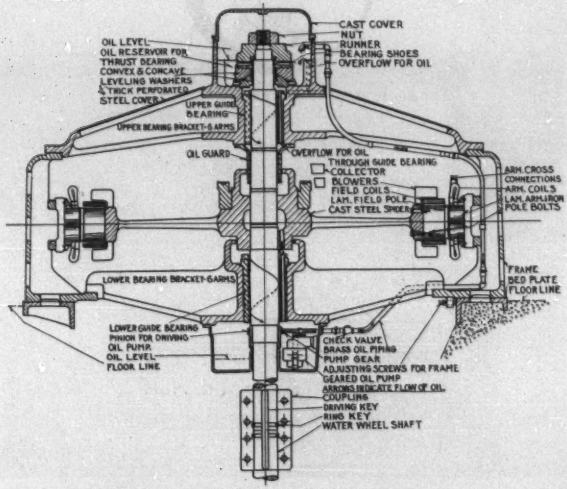


Parts of a Kingsbury thrust bearing.

ments being free to tilt, so that when the upper plate rotates in the direction shown in Fig. 51, the lower plates tilt and the oil wedge is formed as indicated. Such a bearing will carry an average load of 350 pounds per square inch, which is about seven times the safe value for an ordinary thrust bearing.

Fig. 53 shows the arrangement of the guide and thrust bearings of such a vertical generator, Fig. 54 shows the very substantial support used to carry the weight, and Fig. 55 shows

FIG. 53.

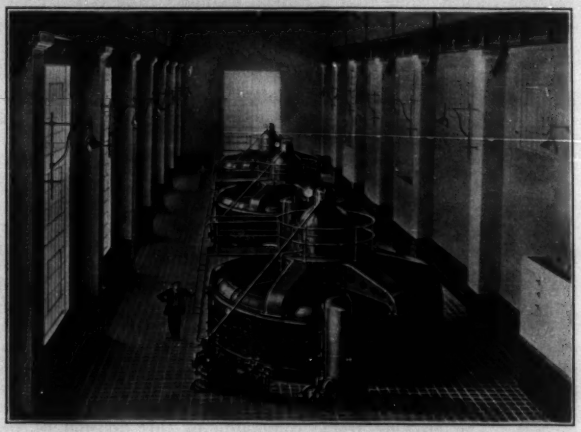


Section of Westinghouse generator with two guide bearings.

one method adopted to force the air into the centre of the long core of these machines. The core length of water-wheel generators of large output is generally longer than it would be for engine-driven units, because the diameter has to be kept small so that the stresses due to centrifugal force will not be excessive should the generator run away, due to faulty operation of the governing mechanism of the water-wheel.

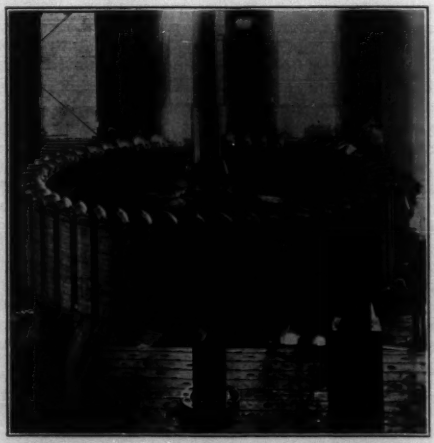
It is generally assumed that the cost and weight of a machine for a given kilowatt output go down as the speed is increased.

FIG. 54.



Three 7800-kv.a., 144-r.p.m. vertical generators with Kingsbury thrust bearings.

FIG. 55.



Rotor for a 10,000-kv.a., 144-r.p.m. vertical generator.

It is true that the value of D^2L decreases, but when the speed reaches such a value that a radical change in the type of construction becomes necessary, as for example when one has to change from the simple cast-steel spider with bolted-on poles to the expensive construction shown in Fig. 45, where the rotor is built up of steel plates, then the labor cost becomes a larger proportion of the total cost, and the factory cost of the machine will not always be reduced.[16]

(*To be continued.*)

America's Longest Railway Tunnel. ANON. (*The Contract Record*, vol. 31, No. 21, p. 449, May 23, 1917.)—The Rogers Pass Tunnel, officially known as the Connaught Tunnel, on the line of the Canadian Pacific Railway through Selkirk Range of the Rocky Mountains in British Columbia, was placed in service on December 9, 1916. The completion of the Connaught Tunnel is without doubt the most notable achievement in the art of tunnelling ever accomplished on the American continent. To complete a rock tunnel, five miles long, in practically three years, under conditions by no means easy, is an undertaking that might well be termed a brilliant success. The growing traffic congestion of this division of the Canadian Pacific Railway lines made the greatest speed construction essential. To meet the urgency demanded by the railway, methods somewhat removed from the conventional were obviously a necessity.

The rapidity of headway was a result of the combination of two elements—a new mode of heading attack and a revised plan of enlargement. In both of these distinct progress is evident upon the practices heretofore accepted. First, a pioneer bore, inaugurated as an experiment, was looked upon with distrust by many authoritative tunnelling engineers, because it did not follow the precedent set by prior rock tunnelling. The enlargement operations further demonstrated the success of progressive ideas. The adoption of a central heading of such size as to permit radial drilling for the final enlargement proved its value, as the speed of driving, averaging 16 to 20 feet daily, constituted a record. Blasting in rings on planes perpendicular to the tunnel axis, although an innovation, contributed to phenomenal progress. Engineers throughout the world have expectantly watched the progress of this experiment. The experiment has been successful, stereotyped processes are at least doomed to revision, and the achievement at Rogers Pass will be an incentive for still further progress in this important branch of engineering.

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[16] Behrend, *Electrical Review*, New York, vol. 45, September 10, 1904 (p. 375).

THE PHYSICAL BASIS OF COLOR-TECHNOLOGY.*

BY

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One of the most annoying features of dyes is the extreme rarity of pure blue dyes. Nearly all blue dyes, Table VII, transmit the extreme red rays quite freely, and the scarcity of blue-green dyes which are not dichroic makes it difficult often to find a combination which transmits only the violet rays. In extremely high concentrations or great depths some blue dyes effectually absorb most of the extreme red rays.

In Table VIII are presented a number of spectral analyses grouped under the common name of purple for the purpose of classification. An interesting case is that of ethyl violet in gelatine, both wet and dry. After the dyed gelatine, which was flowed on clear glass, had set, and while still wet, the spectral analysis was made. The sample was then allowed to dry and another spectral analysis was made. On plotting these data a decided difference in the spectral transmission curves is seen, as indicated by the numerical data. The wet specimen is decidedly more reddish than when dry, and an actual shift in the absorption band takes place on drying. Although not definitely established, this may be explained as due to a difference in the refractive index of the solvent in the two cases. The data are corrected for reflections from the gelatine and glass surfaces.

In Table IX are presented spectral analyses of dyed gelatine filters before and after fading by exposure to solar radiation. Such data are of special interest in many cases, and it appears of interest to make a thorough study of the fading of dyes with the aid of spectral analyses. Certainly no great amount of information is available regarding the relation of the spectral character of radiation to the spectral deterioration of dyes or the relation of either of these to the chemical composition. Some work along this line is in progress. Incidentally, the testing of dyes under illuminants containing ultraviolet rays of extremely short wavelengths which are practically absent in solar radiation at the

* Concluded from page 93, July issue.

TABLE IV.

Spectral Transmission Factors of Red Dyes.

	0.44μ	0.46μ	0.48μ	0.50μ	0.52μ	0.54μ	0.56μ	0.58μ	0.60μ	0.62μ	0.64μ	0.66μ	0.68μ	0.70μ
Carmen ruby opt.	....	....	....	....	....	....	....	....	....	0.04	0.18	0.37	0.49	0.60
Amido naphthol red.	....	....	....	....	....	....	....	....	0.04	.38	.75	.92	.96	.96
Coccinine.	....	....	....	....	....	....	....	0.04	.56	.96	.98	.98	.98	.98
Erythrosine.	0.06	....	....	....	....	....	0. 1	.53	.90	.95	.96	.96	.96	.96
Hematoxyline.	.01	0.03	0.07	0.13	0.14	0.12	.13	.25	.44	.54	.63	.73	.78	.82
Hematoxyline.	....	....	....	....	....	....	....	.01	.02	.04	.09	.15	.21	.25
Alizarine red.	.01	.01	.02	.03	.04	.06	.11	.22	.39	.54	.65	.72	.77	.79
Acid rosolic (pure).	.04	.03	.01	....	....	....	.02	.38	.78	.88	.90	.91	.92	.92
Rapid filter red.	....	....	....	....	....	.01	.10	.47	.86	.95	.96	.96	.96	.96
Aniline red fast extra A.	....	....	....	....	....	.02	.12	.34	.55	.72	.84	.88	.90	.92
Pinatype red fast.	....	....	....	....	....	....	....	....	.11	.35	.55	.65	.68	.69
Eosine (yellowish).	....	....	....	....	....	....	....	....	.06	.40	.63	.74	.82	.85
Eosine.	....	....	....	....	....	....	.01	.54	.87	.93	.92	.92	.92	.92
Naphthalinrot in absolute alcohol.	....	....	....	....	....	....	....	....	.06	.28	.43	.50	.57	.61
Rose bengal.	.80	.70	.34	.06	.01	....	.14	.82	.96	.97	.98	.98	.98	.98
Rose bengal.	.01	....	....	....	....	....	....	.09	.57	.83	.89	.92	.94	.96
Cobalt ammonium sulphate.	.60	.56	.48	.37	.38	.53	.70	.82	.86	.90	.90	.90	.90	.89
Cobalt nitrate.	.69	.51	.40	.31	.32	.48	.67	.82	.87	.90	.90	.90	.90	.90

TABLE V.

Spectral Transmission Factors of Yellow Dyes.

	0.44μ	0.46μ	0.48μ	0.50μ	0.52μ	0.54μ	0.56μ	0.58μ	0.60μ	0.62μ	0.64μ	0.66μ	0.68μ	0.70μ
Tartrazine	....	....	....	....	0.07	0.52	0.75	0.86	0.91	0.95	0.96	0.97	0.98	0.98
Chrysoidin	....	....	....	....	....	....	....	....	.02	.23	.50	.71	.79	.79
Aurantia	....	....	....	....	....	.03	.23	.53	.82	.92	.96	.96	.96	.96
Aniline yellow phosphine	....	....	....	....	.02	.20	.43	.60	.67	.75	.81	.85	.86	.87
Fluorescein	0.15	0.01	....	....	.48	.91	.97	.98	.98	.98	.98	.98	.98	.98
Aniline yellow fast S	....	....	0.01	0.07	.43	.84	.96	.96	.96	.96	.96	.96	.96	.96
Methyl orange indicator	....	....	....	....	....	....	.01	.31	.70	.79	.80	.81	.81	.81
Auramin	....	....	.01	.39	.77	.83	.84	.86	.87	.88	.90	.92	.93	.93
Uranine	.15	.01	....	.01	.58	.96	.97	.97	.97	.97	.97	.97	.97	.97
Uranine naphthaline	....	....	....	.04	.53	.77	.82	.83	.84	.85	.86	.86	.87	.87
Orange B naphthol	....	....	....	....	....	.01	.43	.88	.95	.96	.97	.97	.97	.97
Safranine	....	....	....	....	....	....	....	....	.03	.27	.64	.85	.93	.93
Martius gelb	....	....	....	.01	.43	.84	.91	.94	.95	.95	.95	.95	.95	.95
Naphthol yellow	....	....	.01	.18	.74	.91	.96	.97	.98	.98	.98	.98	.98	.98
Potassium bichromate, sat. sol.	....	....	....	....	....	.10	.60	.84	.88	.89	.89	.89	.89	.88
Cobalt chromate	.17	.36	.62	.82	.88	.90	.92	.93	.95	.96	.96	.96	.96	.95

TABLE VI.

Spectral Transmission Factors of Green Dyes.

	0.44μ	0.46μ	0.48μ	0.50μ	0.52μ	0.54μ	0.56μ	0.58μ	0.60μ	0.62μ	0.64μ	0.66μ	0.68μ	0.70μ
Naphthol green	0.02	0.04	0.07	0.21	0.30	0.36	0.29	0.16	0.07	0.02	0.01	....	....	....
Brilliant green	.04	.39	.69	.52	.23	.04	....	....	....	....	....	0.02	0.23	0.64
Filter blue-green	.35	.49	.64	.70	.60	.37	.13	.02	....	....	....	....	....	....
Filter blue-green	.06	.14	.23	.40	.26	.08	.01	....	....	....	....	....	....	....
Malachite green	....	.12	.20	.08	.01	....	....	....	....	....	....	....	.12	.50
Malachite green	....	.01	.04	.01	....	....	....	....	....	....	....	....	.02	.23
Malachite green	....	....	.01	....	....	....	....	....	....	....	....	....	....	.10
Saurgrün	.03	.29	.57	.57	.39	.19	.04	.01	....	....	....	....	.04	.30
Methylengrün	.28	.31	.32	.26	.17	.07	.02	.01	....	....	....	....	.03	.28
Methylengrün	.14	.16	.17	.13	.06	.01	....	....	....	....	....	....	.02	.14
Aniline green naphthol B	.02	.06	.14	.24	.34	.40	.32	.14	.04	.01	....	....	....	....
Aniline green naphthol B	....	....	.02	.06	.10	.15	.09	.02	....	....	....	....	....	....
Neptune green	....	.40	.63	.41	.13	.01	....	....	....	....	....	....	....	.05
Neptune green	....	.19	.36	.18	.02	....	....	....	....	....	....	....	....	.02
Cupric chloride	.77	.84	.89	.92	.92	.89	.80	.67	.52	.36	.19	.06	.02	....

TABLE VII.

Spectral Transmission Factors of Blue Dyes.

	0.44μ	0.46μ	0.48μ	0.50μ	0.52μ	0.54μ	0.56μ	0.58μ	0.60μ	0.62μ	0.64μ	0.66μ	0.68μ	0.70μ
Turnbull's blue	0.58	0.60	0.56	0.51	0.38	0.28	0.18	0.09	0.05	0.03	0.01	....	....	....
Victoria blau	.52	.23	.09	.01	....	....	....	....	....	.01	.04	0.21	0.49	0.73
Prussian blue (soluble)	.66	.71	.76	.69	.60	.46	.32	.20	.12	.07	.05	.03	.03	....
Prussian blue (soluble)	.06	.09	.09	.05	.02	.01	....	....	....	....	....	....	....	....
Wässer blau	.89	.75	.51	.26	.07	.01	....	....	.01	.02	.06	.18	.37	.60
Wässer blau	.85	.66	.42	.17	.03	.01	....	....	....	.01	.03	.10	.26	.48
Resorcine blue	.25	.18	.06	.02	.01	....	....	....	.01	.02	.14	.41	.64	.72
Toluidin blau	.66	.31	.13	.03	.01	....	....	....	....	....	.01	.04	.16	.40
Patent blue	.83	.91	.84	.76	.65	.46	.24	.08	.02	....	....	.06	.42	.78
Patent blue	.15	.25	.17	.05	....	....	....	....	....	....	....	....	....	.12
Dianil blue	.77	.69	.59	.48	.35	.24	.15	.09	.05	.05	.07	.14	.29	.53
Dianil blue	.38	.30	.18	.10	.04	.01	....	....	....	....	....	....	.02	.12
Filter blue	.84	.79	.66	.44	.27	.17	.14	.19	.36	.56	.74	.81	.88	.92
Filter blue	.35	.29	.18	.05	....	....	....	....	.02	.08	.23	.44	.62	.71
Aniline blue, methyl	.92	.88	.78	.52	.27	.09	.03	.02	.02	.04	.08	.16	.25	.45
Aniline blue, methyl	.44	.31	.13	....	....	....	....	....	....	....	....	....	....	....

TABLE VIII.

Spectral Transmission Factors of Purple Dyes.

	0.44μ	0.46μ	0.48μ	0.50μ	0.52μ	0.54μ	0.56μ	0.58μ	0.60μ	0.62μ	0.64μ	0.66μ	0.68μ	0.70μ
Ethyl violet in gelatine (dry)	.97	.87	.67	.28	.04	....	....	....	....	.05	.33	.73	.88	.91
Ethyl violet in gelatine (wet)	.83	.79	.45	.07	.01	....	0.01	0.03	0.05	.15	.42	.76	.91	.93
Magenta	.21	.08	02	.01	....	....	.01	.22	.73	.93	.97	.97	.97	.97
Magenta	....	....	....	....	....	....	....	....	.07	.48	.81	.92	.95	.95
Gentiana violet	.89	.83	.64	.44	.26	.19	.15	.10	.13	.42	.75	.92	.93	.94
Gentiana violet	.11	.01	....	....	....	....	....	....	....	....	.01	.15	.48	.66
Rosazeine	.50	.28	.02	....	....	....	....	.06	.55	.90	.98	.98	.98	.98
Rosazeine	....	....	....	....	....	....	....	....	....	07	.54	.90	.95	.95
Iodine (dense)	....	....	....	....	....	....	....	....	....	....	.01	.03	.11	.23
Rhodamine B	.81	.71	.45	.13	.02	....	....	.23	.83	.96	.96	.96	.95	.94
Acid violet	.84	.76	.68	.50	.33	.26	.27	.34	.49	.70	.84	.96	.96	.96
Acid violet	.29	.08	.01	....	....	....	....	.01	.09	.32	.63	.84	.94	.94
Cyonine in alcohol	.07	.01	....	....	....	....	....	....	....	....	....	.01	.13	.23
Xylene red	.39	.23	.01	....	....	....	....	.01	.27	.79	.97	.97	.97	.96
Xylene red	....	....	....	....	....	....	....	....	.01	.31	.79	.96	.96	.95
Methyl violet B	.25	.04	....	....	....	....	....	....	....	....	.03	.26	.63	.89

TABLE IX.

Spectral Transmission Factors of Faded and Unfaded Gelatine Filters.

	0.44μ	0.46μ	0.48μ	0.50μ	0.52μ	0.54μ	0.56μ	0.58μ	0.60μ	0.62μ	0.64μ	0.66μ	0.68μ	0.70μ
Erythrosine	.81	.52	.14	.02	....	.02	.16	.65	.95	.96	.96	.96	.96	.96
Erythrosine (faded)	.76	.58	.27	.10	0.02	.07	.34	.78	.94	.95	.95	.95	.95	.95
Aniline yellow fast S	.51	.57	.66	.82	.94	.97	.98	.98	.97	.97	.97	.95	.93	.91
Aniline yellow fast S (faded)	.58	.62	.67	.81	.90	.95	.95	.95	.95	.95	.95	.95	.92	.90
Neptune green	.21	.41	.44	.40	.28	.15	.04	....	....	....	....	....	.06	.35
Neptune green (faded)	.10	.60	.75	.65	.43	.15	.02	....	....	....	....	....	....	.12
Green for screens	.15	.34	.72	.93	.93	.83	.69	.45	.25	.12	.04	.05	.26	.6
Green for screens (faded)	.15	.38	.70	.89	.86	.77	.67	.48	.32	.19	.09	.13	.42	.73
Ethyl violet	.74	.69	.33	.03	....	....	....	....	....	....	.06	.40	.72	.83
Ethyl violet (faded)	.67	.53	.34	.12	.02	....	....	....	....	.02	.21	.54	.77	.85
Methylenblau	.79	.75	.59	.43	.27	.11	.03	.01	....	....	....	.01	.13	.44
Methylenblau (faded)	.58	.49	.40	.29	.19	.15	.10	.09	.09	.11	.22	.35	.46	.57
Rosazeine	.97	.97	.96	.77	.54	.31	.17	.91	.95	.96	.98	.98	.95	.94
Rosazeine (faded)	.97	.97	.96	.89	.72	.73	.79	.92	.95	.95	.98	.98	.95	.94

earth's surface or in artificial illuminants as commonly encountered is open to criticism. Spectral analysis has not been sufficiently utilized in permanency tests to warrant all the conclusions which have been drawn in this matter, although some excellent work has been done.[7] Mr. Mott has shown that the results with the "snow-white" flame arc in dye-fading are practically the same as those obtained in daylight.

APPLICATIONS OF SPECTRAL ANALYSES OF DYES.

The uses for spectral analyses of dyes are manifold, as in the case of any class of colored media. In general they provide a physical basis for systematic color-mixture, besides providing the necessary information for choosing dyes for many purposes. In many aspects of color-technology only the integral or subjective color is finally of interest, but the author cannot refrain from emphasizing that even in such cases an intimate knowledge of colored media and their mixtures cannot be attained without spectral analyses, and that the combination of dyes becomes systematic with such data available.

With spectrophotometric apparatus well maintained, a complete spectral analysis can be made in about an hour, although there is much room for improvement in such apparatus which will result in the saving of time. However, this is not a serious matter, because for a given coloring material only one analysis need be made, as will be shown later, to provide information for all degrees of concentration or depth of solution. The author has available hundreds of spectral analyses which, after once obtained, are a perpetual source of information.

Laws.—In order to simplify the study of coloring media, especially dyes and colored glasses, several simplifications have been made. These are based on theory and have been confirmed by experiment on a few typical specimens. In order to develop this procedure it is necessary to revert to some of the established laws. Lambert first stated that all layers of equal thickness of a transparent medium absorb equal fractions of the radiant energy which enters them. This is true for homogeneous or monochromatic radiation, but cannot be applied to the total absorption of radiant energy of many wave-lengths or of extended spectral character. It follows from Lambert's law that if the thickness of the ab-

[7] W. R. Mott, *Trans. Amer. Electrochem. Soc.*, 1915.

sorbing medium increases in arithmetical progression the radiation transmitted should decrease in geometrical progression.

Let J be the intensity of radiation of a given wave-length entering a layer dl, then—

$$-\frac{dJ}{dl} = kJ$$

On integrating this we obtain:

$$J = J_o e^{-kd}$$

where J_o is the original intensity, J the intensity after traversing a thickness d, and k is a constant depending upon the substance and upon the wave-length of the radiant energy. Various terms have been applied to this factor, such as absorption-coefficient. In logarithmic form this equation is expressed as:

$$\text{Log}\frac{J}{J_o} = \log T_\lambda = -k_\lambda d \log e = -\epsilon_\lambda d$$

where T_λ is the transmission factor for energy of wave-length λ, and the subscripts, λ, indicate the factors which vary with the wave-length. Beer deduced the law that the absorption is the same function of the concentration of a dispersing absorbing substance as of the thickness of a single substance, which may be expressed thus:

$$J = J_o A_\lambda^{cd} \text{ or } T_\lambda = A_\lambda^{cd} \text{ or } \log T_\lambda = cd \log A_\lambda$$

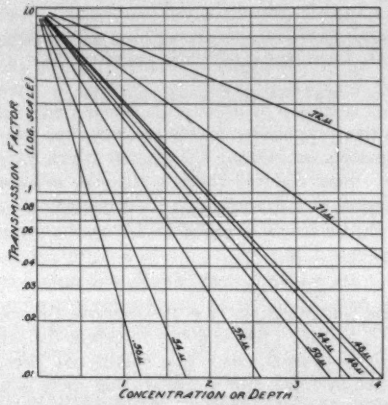
where c is the concentration, A is the transmission-coefficient or transmissivity, and the other symbols represent the same factors as in the foregoing equations. The validity of Beer's law has been questioned by some, and it appears that there is some doubt as to its validity in such cases as colloidal solutions. This law appears to hold when the absorbing power of a molecule is uninfluenced by the proximity of other molecules. Obviously, if any change takes place in the condition of the dispersed substance on altering the concentration the law will not hold. Incidentally there is work to be done on the validity of this law in the cases of "colloidal" glasses. Lambert's law appears to be firmly established.

In so far as the foregoing laws are valid (and it appears that this is true for all practical purposes such as described in this paper), for a given solution $\log T_\lambda$ is proportional to d, and for a given depth, or containing cell, $\log T_\lambda$ is proportional to c. By the use of coördinate paper having a logarithmic scale along one

axis and a uniform scale along the other a great deal of interesting data can be obtained from one spectral analysis.

By means of the foregoing mathematical relations the spectral analyses of colored solutions (and colored glasses) of any thickness and concentration can be obtained from two determinations of spectral character, which often may be reduced in actual practice to a single determination. Such a method has been found exceedingly practicable in preliminary reconnoitering in search of combinations of dyes for filters, in the development of colored

FIG. 10.



Relation between spectral transmission-factor and depth or concentration of a solution of methylengrün.

glasses, and in the study of many problems arising in color-technology.

Some examples will suffice to illustrate the uses of this scheme in practice. Assume a solution of methylengrün of either known or unknown concentration. A cell of a known thickness is filled with the solution and a spectral analysis is made. For such a purpose a fairly low concentration or small depth is chosen, so that radiations of all wave-lengths which are of interest are appreciably transmitted. On logarithmic paper, as previously described, a plot is made, as shown in Fig. 10, the transmission factors [8] from the spectral analysis being plotted on the logarith-

mic scale vertically above the arbitrarily selected point on the abscissa axis in this case taken as unity. The abscissæ scale may represent either concentration or depth and may be either a relative or an absolute scale. Straight lines are drawn through the points to a common point on the ordinate axis representing complete transparency or unity on this logarithmic scale. This is the common point if corrections have been made for surface reflections in the cell or from the glass surfaces in the case of a colored glass. If these corrections have not been made, the common point usually will be near 0.92 on the "transmission axis" if two surface reflections must be accounted for. Each straight line represents the relation of log T_λ and depth or concentration for a certain wave-length. By extending these lines the spectral characteristic of any depth or concentration may be read from the corresponding vertical line. If the original spectral analysis has been made with care, such a simple plot yields a vast amount of data.

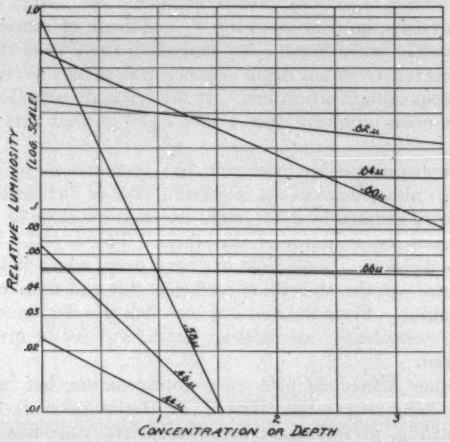
Dichromatism.—Methylengrün has been chosen in Fig. 10 because it also illustrates the interesting case of dichromatism so commonly exhibited by dyes. It is seen that the slope of the line for 0.72μ is less than any of the others. This is proof that the dye is a dichroic. Some lines are very steep, which indicates a large value of the absorption-coefficient for radiation of these wave-lengths. From the plot it is seen that this dye, in solutions of high concentration or of great depth, will not be green, but will be red.

Another interesting plot, of a similar nature, but including relative luminosity-values instead of transmission factors, is shown in Fig. 11 for rosazeine. The spectral transmission factors for the spectral analysis used were multiplied by the visibility of radiation in each case (using Nutting's data) and plotted vertically above the point designated by unity on the concentration or depth scale. Instead of drawing straight lines representing various wave-lengths to a common point on the ordinate axis, each line is drawn to a point of this axis corresponding to the relative visibility of radiation of the particular wave-length. The

[1] NOTE.—Transmission factor is defined by the Illuminating Engineering Society as the ratio of the transmitted to the incident flux. In the present use the surface reflections are eliminated in order to make the data more useful, so that the same definition applies here for the given thickness if the body is assumed to be immersed in medium of the same refractive index.

ordinate axis is now a logarithmic scale of relative luminosity. By extending these straight lines a graphical picture of spectral luminosity of the dye-solution is obtained for any concentration of depth. It is seen that this solution in great depth or high concentration becomes deep red, because the slopes of the lines become less with increasing wave-length after the absorption band of a weak solution or small depth is passed. Incidentally it will be noted that the slope of line 0.44μ is less than that of 0.58μ, which shows that in low concentrations or in relatively small

FIG. 11.



Relation between spectral luminosity and depth or concentration of a solution of rosazeine.

depths of a higher concentration the solution is purple; that is, it has an absorption band somewhere between 0.44μ and 0.60μ. Only a few wave-lengths have been used for the sake of clearness.

Complete Representation of the Graphical Method.—In reality the schemes illustrated in Fig. 10 and 11 are only completely illustrated by means of a solid, of which, for example, Fig. 10 represents a projection upon the face of the solid bounded by the logarithmic "transmission" scale and the concentration or depth scale. A model of this tri-dimensional diagram can be easily made and should be instructive. An attempt is made in

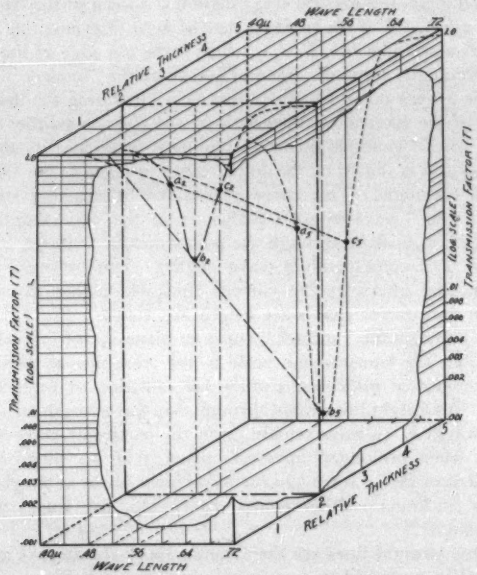
Fig. 12 to illustrate the relations between transmission factor, wave-length, and concentration or thickness. For this purpose the spectral analysis of a thin piece of gold red glass was chosen. Many of the cross-section lines have been omitted for the sake of clearness. The scales are designated and the thickness of the specimen of gold ruby glass is assumed to be 2 units on the relative thickness scale. In plane 2, represented by the dash-dot vertical rectangle, the spectral transmission is shown in the dash-dot curve, $a_2 b_2 c_2$. For the limiting case of zero thickness this curve becomes a straight line, $T = 1$, which is the top edge of the foremost rectangle, plane 0. Several points of the "master" curve in plane 2 were taken for the purpose of illustrating the determination of the spectral characteristic of the glass at another thickness. In this example thickness 5 units is taken and its spectral transmission is shown by the dotted curve in plane 5, the farthest vertical rectangle. This curve is obtained by drawing straight lines in the "wave-length" planes from the wave-lengths on the upper front scale through the points on the "master" curve in plane 2 of corresponding wave-lengths. Thus where a given straight line intersects the various thickness planes the transmission factors for that wave-length are found. For example, b_2 is a point on the "master" curve in plane 2, and its value as read from the transmission scale is the transmission factor of this specimen of thickness, 2 units, for radiation of wave-length 0.52μ. A straight line drawn through this wave-length on $T = 1$ and through b_2 (always remaining in the particular wave-length plane) when prolonged intersects plane 5 at b_5, which is the transmission factor for 0.52μ for a specimen of the same glass of 5 units thickness. Other points, a_5, c_5, etc., are found in the same manner.

These straight lines are the same as those shown in Fig. 19; in fact, Fig. 19 would be seen on viewing the solid, Fig. 12, from the right-hand side. A model of this solid made of wires and painted to represent the spectral colors should be instructive.

In Fig. 11 luminosity values were treated in a manner similar to the transmission values in Fig. 10. These also can be completely represented by a solid in a manner similar to that shown in Fig. 12, excepting that the vertical scale must represent logarithms of luminosity. In the limiting case of zero thickness the curve will not be the foremost upper horizontal line, but will be

the spectral luminosity curve of radiation and will lie in the foremost vertical plane On viewing such a solid in projection from the proper side, Fig. 20 will be seen if the same gold ruby specimen be taken as an example. It appears unnecessary to illustrate this possibility, since the general procedure should be understood from the foregoing. In case the analysis is to be made for a

FIG. 12.



Complete relation between thickness, wave-length, and transmission-factor for a gold ruby glass.

particular illuminant the limiting curve in the foremost vertical plane will be the luminosity curve of the illuminant.

One of the points which is emphasized in dealing with colored media in the foregoing manner is that the spectral transmission and reflection factors are never zero, but are merely relatively low for some wave-lengths as compared with others. This is often forgotten when spectral analyses are made with instru-

ments, because when the luminosity falls below the threshold the transmission factor is considered to be zero; however, the threshold depends upon the intensity of illumination or upon the brightness of the light-source.

SPECTRAL ANALYSES OF GLASSES.

In the development of colored glasses for the variety of practical applications the spectral analyses are extremely valuable and often essential. By means of such data these coloring elements can be mixed computationally to obtain the desired spectral characteristic. From very meagre data on the chemical composition from one melt fairly definite strides toward realization may be made in succeeding melts. Of course, there are chemical considerations which sometimes alter the predictions based on computation; however, such a procedure forms a most definite working basis. In the combination of glasses for special filters, lighting effects, etc., the computational method often saves time and provides definite data. Sometimes only the subjective color is desired, but even in these cases spectral analyses of elemental colorings provide the basis for manipulating the available vitrifiable colored media in a manner analogous to the combination of pigments.

In the manufacture of colored glass there is a limited number of coloring materials available, and when the glass must be limited to one general composition, such as soda lime, for example, the colors which are possible of attainment are further limited. However, by combining various coloring materials the variety of colored glasses can be enormously extended to meet the requirements of science and art.

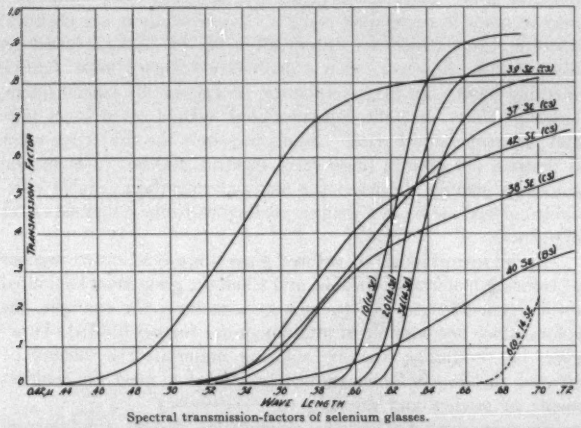
In this paper the spectral analyses of a few fundamental colored glasses will be presented, and also the results of a few simple combinations. The record number of the specimen is placed before the symbol of the coloring metal, such as 37 Se. If different relative thicknesses of the specimen are presented, a number is placed before the designation proper, as 10 (37 Se) indicates 10 units of thickness (or of concentration), CS indicates lime soda glass, PS lead soda, BS barium soda, P lead, etc.

Red.—Selenium, copper, and gold are commonly used for producing red glasses. In Fig. 13 are shown the spectral analyses of a number of selenium glasses. It is seen that some of these are yellow in appearance and vary from this to a deep red. The

composition of the mix is sometimes of considerable influence upon the final color. Specimen 14 Se, shown in relative thickness, 10, 20, and 34, was of unknown composition, but the coloring element was selenium. This is a remarkable specimen. Cobalt blue glass (Fig. 17) transmits a deep red band, so a combination of dense cobalt blue and selenium glasses isolates a deep-red band, as seen in 6 Co + 14 Se, Fig. 13.

By computations similar to those presented in the case of pigments (substituting transmission factors, T_λ, for reflection factors R_λ) the efficiency of such a combination in transmitting

FIG. 13.



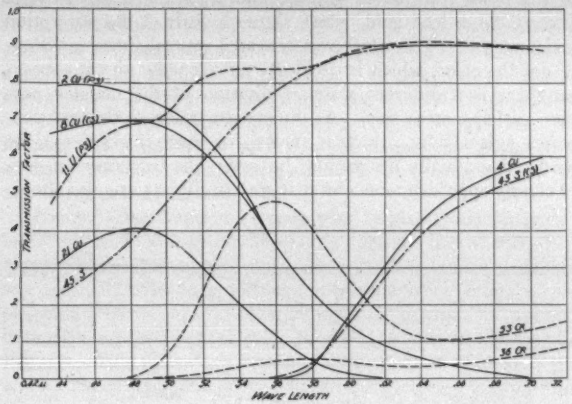
Spectral transmission-factors of selenium glasses.

only a deep-red band can be compared with that of a very dense selenium, gold, or copper glass. Unfortunately, at the ends of the visible spectrum the visibility data are difficult of determination and have been the least investigated; however, Hyde, Cady, and Forsythe [9] have determined the visibility at the extreme red end of the visible spectrum with great care.

In Fig. 14 is shown the spectral characteristic of a copper-red glass, 4 Cu, and in Fig. 15 the spectral analyses of gold glasses are presented. Gold produces a beautiful pink in low concentrations (or in thin layers) and deep red in the higher ones (or

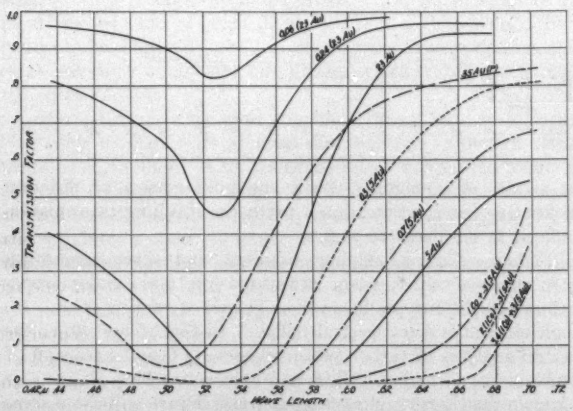
[9] *Astrophysical Journal*, 42, p. 285, 1915.

FIG. 14.



Spectral transmission-factors of copper, sulphur, chromium, and uranium glasses.

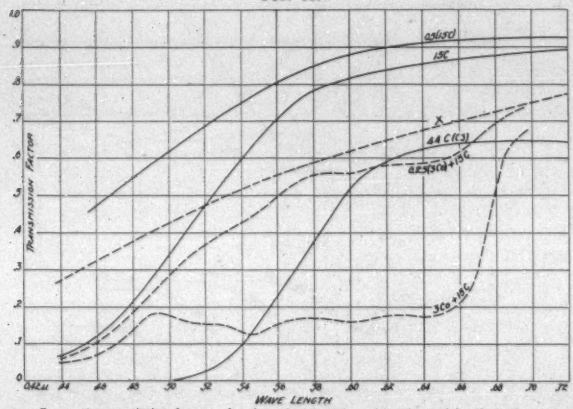
FIG. 15.



Spectral transmission-factors of gold glasses and combinations of cobalt.

in thicker layers). The absorption band is seen to be near 0.53μ for the more transparent glasses, and it is interesting to note glass 35 Au, a lead gold, which shows a shift in the absorption band to 0.50μ. This glass was reheated several times in bringing out the color, which is decidedly more ruddy, and it appears that there is a different state of division of the metallic particles, perhaps, as to size. As the concentration or thickness increases (glass 5 Au, which is shown for three thicknesses) the blue band gradually disappears; however, the transmission does not closely approach monochromatism. In Fig. 15 are also shown

FIG. 16.



Spectral transmission-factors of carbon glasses and combinations with cobalt glasses.

the results of combining cobalt and gold glasses of different thicknesses (or concentrations), with the resulting transmission confined to the deep-red region.

Yellow.—Carbon, sulphur, uranium, and silver are among those elements which, when introduced into glass under proper chemical conditions, produce yellow glasses of varying color. No single element isolates spectral yellow. In Fig. 16 are shown the spectral analyses of carbon yellow glasses, 15 C and 44 C, and of combinations of carbon yellow and light cobalt blue glasses. It is known that X-rays, ultraviolet and visible rays will cause some clear glasses to become colored. In Fig. 16 is also shown the

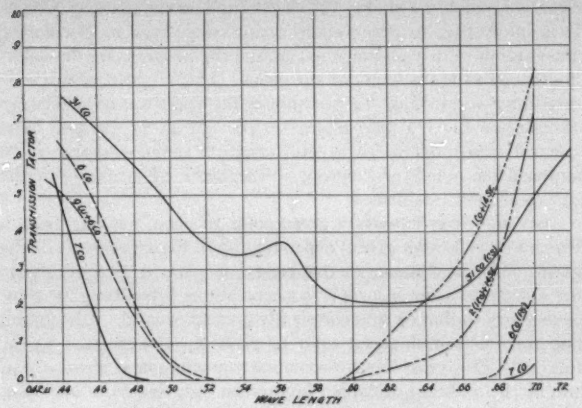
spectral characteristic of a glass *X*, which, though originally clear, was colored a muddy yellow throughout the mass by X-rays. It is interesting to observe the action of X-rays in discoloring glass, for it is easy at times to observe the progress of the coloring through the thickness of the glass. Patterns can be made by this process. In Fig. 14 are shown the spectral characteristics of uranium (11 U) and sulphur (43 S and 45 S) glasses. The spectral transmissions of several uranium samples appear to be kinky in the blue-green region, although the exact nature of the curves are not established.

Green.—Iron imparts a green color to glass, varying from a bluish to a yellowish-green, depending upon the ingredients of the glass. The importance of manganese in glass is as a decolorizing agent, its color in proper concentrations being roughly complementary to that of iron commonly present in sand. Chromium imparts a yellowish-green color to glass, as seen in glass 53 Cr, Fig. 14. This glass has a maximum transmission at about 0.56μ, and by the addition of copper blue-green (glasses 2 Cu and 8 Cu, Fig. 14) this maximum can be shifted toward the shorter wavelengths, depending upon the proportions of the coloring elements. Glass 21 Cu, called signal blue-green, is evidently a copper glass. Glass 36 Cr is a dense chromium green. In order to compare the actual colors under a given illuminant it is well to reduce these curves to luminosity values. If monochromatism is desired, it is often advisable to combine two glasses which transmit a narrow region in common.

Blue.—Cobalt is the most common element used to impart a blue color to glass. Its greatest disadvantage (although sometimes an advantage) is its transmission of a deep-red band, as shown in 6 Co and 7 Co, Fig. 17. This red transmission can be utilized in isolating the deep red, as shown by combining cobalt and selenium or other red glasses, for example 1 Co + 14 Se. An excellent blue glass can be made by combining cobalt with copper blue-green, for the latter effectively absorbs the deep red. The spectral characteristic of such a combination is shown in 9 Cu + 6 Co, Fig. 17.

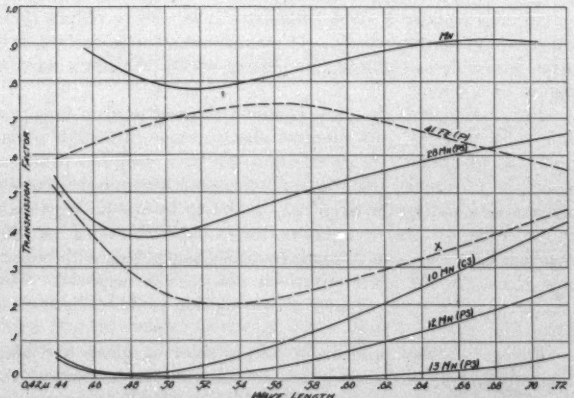
Purple.—Nickel produces a purple color in glass, and also manganese, but the latter is not an efficient purple, because its absorption band is not sharp. Its chief use is to neutralize the green tint due to the presence of iron in the ingredients of glass

FIG. 17.



Spectral transmission-factors of cobalt glasses.

FIG. 18.



Spectral transmission-factors of manganese and iron glasses.

mixes. The spectral characteristic of a glass containing iron is shown in 41 Fe, Fig. 18. It is seen that a manganese glass of proper density is approximately complementary in color to the iron glass. Although the manganese neutralizes the iron in color, the transmission factor of the resultant glass may be seriously reduced. Manganese, though a useful element in glass manufacture, cannot be considered important as a coloring element from the viewpoint of colored glass in general. In *X*, Fig. 18, is shown the spectral characteristic of an originally clear glass which has been colored a deep-purplish hue by exposure to X-rays. Undoubtedly this coloring is due to an effect upon the manganese present in the clear glass. This effect is commonly observed in lamp globes and window glass exposed to strong sunlight. In the former cases it is a very serious defect of glass manufacture, because the author has observed such globes whose transmission has been reduced as much as 50 per cent. after long exposure to intense solar radiation or to that emitted by an arc lamp. It would be far better in such cases as street-lighting glassware to eliminate the manganese and to endure the unneutralized greenish hue of the iron which is unavoidably present.

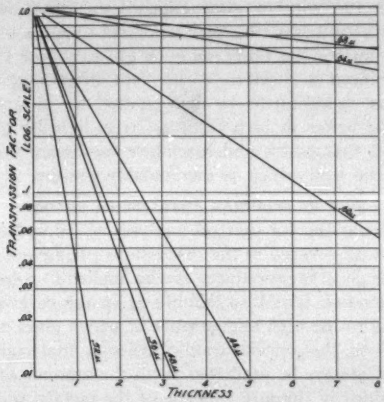
USES OF SPECTRAL ANALYSES OF GLASSES.

The applications for spectral analyses of colored glasses have been fairly well covered in the discussions of pigments and dyes, for the same general procedures can be applied to colored glasses. The concentration is not so definite as in the case of dyes, because, owing to the high temperature at which glass melts and to chemical action, the concentration of coloring material in the final glass cannot always be predicted from the amount of the coloring metal added to the mix. Some of the metals, such as cobalt and copper, under standardized conditions of melting, appear to produce concentrations of coloring material proportional to the amounts of the oxides added to the mix, but in some cases there is doubt as to this proportionality. There is need for systematic study in this direction. In the case of the red glasses, for example gold ruby, which in ordinary manufacture assumes its red color on reheating, the manipulation has considerable effect upon the density of the color. After a colored glass has been obtained it is possible to procure from a single spectral analysis the integral transmission factor for any illuminant, the spectral characteristics of other thicknesses, and those of combinations of these thicknesses with other colored glasses as already outlined.

For the sake of further exemplification, in Fig. 19 are shown the straight-line relations between thickness and transmission factor (for entering radiation) for several wave-lengths for various thicknesses of a gold ruby glass. The relations between luminosity and thickness for this glass are shown in Fig. 20 for various wave-lengths. Fig. 19 is a diagram of what would be seen if the solid represented in Fig. 12 were viewed from the right-hand side.

At this point it is of interest to show the approximation of experimental results to the relations between spectral character and thickness as predicted by theory. This is shown in Fig. 21

FIG. 19.



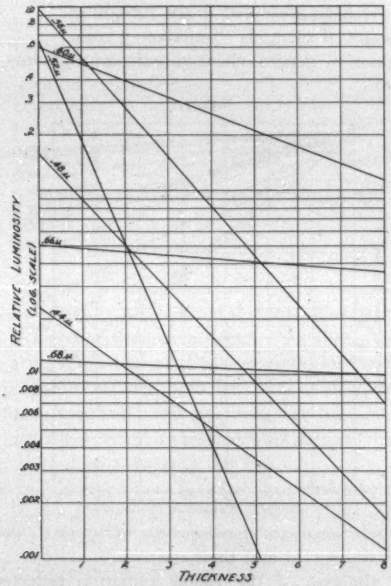
Relations between spectral transmission-factor and thickness of a gold glass (23 Au).

for one of the glasses made during the development of an "artificial-daylight" glass some years ago. The method of graphical analysis was tested because of the desire for a simple method, and the specimen was ground and polished in five thicknesses. The circles show the verification of the theory. In this case correction had not been made for surface reflection, so the straight lines must be drawn to a point near 0.92 on the transmission axis. Incidentally it is of interest to note that, previous to the adoption of this method, samples of melts were ground in the form of thin wedges and spectral analyses were made at various thicknesses. It is seen that the graphical method enormously reduces

the amount of work in order to obtain the data necessary for such studies.

In developing a colored glass for a specific purpose various factors are considered, such as the illuminant to be used and the result to be obtained. From these an ideal spectral transmission curve is determined, and by means of a few spectral analyses of different colored glasses, bearing in mind the chemical consider-

FIG. 20.



Relations between spectral luminosity and thickness of a gold glass (23 Au).

ations if a mixture is finally necessary, various combinations can be made with the aid of the graphical method.

Often the ultraviolet and infra-red spectral transmissions are of interest, and these are made in the manner already described. The data on a coloring element are not considered to be sufficiently complete for record if the ultraviolet transmission is not studied at least qualitatively, and in some cases the infra-red

transmission is investigated. It appears unnecessary to discuss these further, for the aim of this paper has been realized. Various data have been presented with the hope that they will be helpful to others, and various uses of physical data have been discussed with a view to presenting only aspects that are uncommonly appreciated and which have been developed in practical work in color-technology.

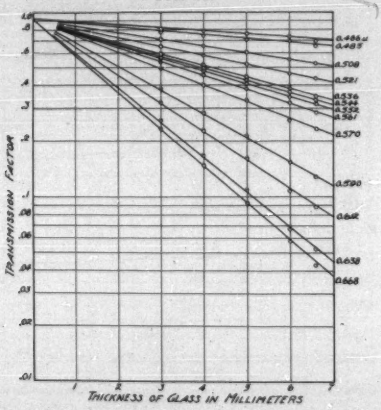
SUMMARY.

There have been presented in the foregoing:

A discussion of methods of analyzing color.

A discussion of general characteristics of pigments, dyes, and colored glasses.

FIG. 21.



Test of the relation between spectral transmission-factor and thickness of a blue-green glass.

Laws of absorption and their uses.

Spectral analyses of the visible radiation reflected by pigments and transmitted by dye-solutions and colored glasses.

A discussion of the uses of such data.

A general emphasis of the importance of a physical basis in color-technology.

I wish to acknowledge the assistance of Mr. H. H. Kirby in obtaining the data and preparing the illustrations.

CLEVELAND, OHIO,
April 28, 1917.

SUBMARINES IN PERIODICAL LITERATURE FROM 1911 TO 1917.

COMPILED BY

HELEN R. HOSMER.

Introduction
I. *General*
- History of Development
- Military Considerations
- Dimensions
- Specific Boats

II. *Propulsion*
- Engines
- Storage Batteries

III. *Armament*
- Torpedoes
- Guns

IV. *Special Equipment*
- Periscope
- Signalling

V. *Builders*
- Boat Builders
- Engine Builders

VI. *References*

INTRODUCTION.

In this outline of publications discussing the submarine, an attempt is made to present the general status of current knowledge on the subject rather than give detail. At the same time such exact data are included as might be required by the person who, approaching the problem as a stranger, may wish to get an idea of the magnitudes involved. More exhaustive inquiry will always demand consultation of the original publications, to which this paper may, in that case, serve as an index.

No material is given here that is not quoted directly from the references under consideration. Where ambiguity has existed, the form of expression also has been followed rather than risk further error by imposing the interpretation of the compiler.

Many short notes and general papers have been omitted from notice when it has seemed that they would not add value to the collection.

Also, none of the many articles appearing in the *Scientific American* have been quoted. This last is for the reason that such articles generally contain exactly the same data that are found in the technical papers, and in an already abstracted form. Where

other library facilities are lacking, a very great deal of information may be gained by the consulting of the files of this journal.

I. GENERAL.

History of Development.
Military Considerations.
Dimensions.
Specific Boats.

Bedell[1] (1917) gives a general description of the gross characteristics of the submarine and a brief history of its development. He mentions that vision from the periscope through the water, in the clearest water, does not exceed 100 to 200 feet. In the turbid waters along our shores nothing can be seen 75 feet away.

Kearney's[2] (1915) article is very general in nature and intended to amuse rather than instruct. He outlines the development and purpose of the submarine.

Hinkamp[3] (1915) gives the principal dates in the development of the submarine, and then goes on to a general description of the methods employed in operation. No specific data are included.

In reference[3] (2) (1915) Hinkamp mentions the improvements made since the early days of the submarine in each of its most prominent features.

Woodhouse[4] (1917) states that vision downward from an aeroplane is not affected by the refraction that limits that from a ship. At an elevation of 1000 to 1500 feet the wake of the periscope is plainly visible against the dark water, even when there are white-caps. In clear weather the submarine can be seen at depths from 20 to 100 feet, depending upon the clearness of the water. The foamy wake at the stern is also clearly visible. Painting will not obscure this last. Hundreds of kite balloons sent up from ships are being used as outlooks for submarines.

Lake[5] (1915–1916) introduces a paper upon the future possibilities of the submarine by an historical account of its development. This goes back to Bushnell's American turtle, and gives considerable detail on the construction and operation of

subsequent types. The United States Government first recognized the possibilities of the submarine in 1893 by appropriating $200,000 for building such a boat. Holland's *Plunger* was the result, which failed to meet the requirements of a guarantee such as has never yet been met by any submarine. She never made a submerged run. A great deal of detail concerning the construction and principles affecting operation is given. The problems solved in the building of Lake's *Argonaut* and other contemporary boats are gone into in detail.

Lake[5] believes coast-defence submarines will be found especially valuable. Speed and high tonnage will not be necessary. A boat of 500 tons displacement and a speed of 14 or 15 knots can have comfortable living quarters and carry eight Whitehead torpedoes. Such a boat can be built for one and one-half million dollars. These boats should be equipped to fire in any desired direction submerged. The *Seal* (G-1) is the only one thus far equipped with torpedoes that can be fired to either broadside. If such submarines were stationed at intervals of five miles outside New York Harbor, no ship could pass without being seen by day or heard by means of the Fessenden oscillators or microphones, with which all submarines are now equipped. As these microphones enable code communication up to several miles, the submarines could be in constant communication with each other and with the shore.

Lake believes that the near future will see the building of a high-speed submarine for offensive warfare, equipped with rapid-fire guns of sufficient calibre to deal with merchantmen and with room enough in the superstructure to keep a crew in good condition during a long cruise. This should be capable of at least 25 knots. As the engine situation stands to-day Lake does not believe such a boat of even 20 knots can be developed in less than three or four years. This is due to the fact that no internal-combustion engine suitable for such high speeds has yet been produced. There is no difficulty connected with the functioning of the vessel itself.

Lake suggests the building of 250-ton (submerged displacement), 10-knot submarines, capable of transportation on railroad trucks, for coast defence. These would be somewhat smaller than the present coast-defence submarines, and could be transported

rapidly to any threatened point of our extended seaboard. This would give them a range much greater than possible with our present submarine fleet, of which the best have a radius of action of about 100 miles at five knots, 11 miles at ten and one-half knots, or 24 miles at eight knots. He states that these "amphibious" submarines could be built at a cost of about $300,000 each.

Lake considers that the proposed one man "baby" submarines would, on account of their low speed, limited range of action, and unseaworthiness, be of very little use to-day.

Lake [5] believes that, as it is impossible to see the invisible, submarine cannot fight submarine, and says that, infested as have been the North Sea and English Channel, he knows of no one case where one has succeeded in sinking another. An Austrian submarine did sink an Italian, but the latter was surface cruising.

Lake [5] dismisses as absolutely impracticable the idea that a submerged submarine can be located by an overhead aeroplane, much less successfully attacked, even if so located. He also considers the efficacy of nets as very doubtful. They could be easily evaded by submarines suitably equipped. He mentions at length a mine-laying submarine which he designed and built, but which the government failed to adopt.

Lake [5] states that in the light-surface or decks-awash condition the submarine may sight a ship at ten miles. The periscope at rest is invisible from a ship one-half mile away.

The internal-combustion engines used in surface cruising are very noisy, but the storage battery and motor are practically noiseless.

The United States submarine *Seal,* or G-1, as originally equipped, is the only vessel ever built in the United States with torpedo tubes to fire broadside. She had four torpedo tubes which could be trained and fired to either broadside, both submerged and on the surface. This would enable her to lie at rest and fire, thus eliminating the tell-tale wake of a moving periscope. A periscope of neutral color at rest is almost impossible of detection even at 300 to 400 yards.

Lake intimates that he has devised certain other improvements and tactics as well as methods of protecting ships that it would be unwise to publish.

Laubeuf [6] (1915) explains in detail the differences between the submarine of the earlier type and the submersible, and gives

cross-sections showing the hull construction of the Holland, Lake, Electric Boat Company's, and French Maugas system submarines, and of the Laubeuf, Germania-Krupp, and Laurenti submersibles. Dimensions, displacements, and values of reserve buoyancy are given for each. If the coefficient of reserve buoyancy be defined as the ratio of the reserve buoyancy (equal to the emerged volume of a surface boat) to the total volume of the ship completely immersed, this coefficient is 50 per cent. for ordinary ships, 3 to 7 per cent. for the earliest submarines, 12 to 13 per cent. for the pure submarine type, and 27 to 33 per cent., or even 41 per cent. for the Laubeuf type of submersible. This means that, on the open sea, the last navigates the surface like an ordinary boat, while the submarine, pure and simple, has to withdraw her crew and navigate under the same conditions as when submerged.

The submersibles are slower of submergence, but the time required has been reduced from 28 minutes in the first Laubeuf boat to five minutes in recent boats. The last is stated to meet all military requirements.

In 1900 France was the only power possessing submersibles, and since 1907 she has ceased building any other type. Germany, Italy, Greece, Sweden, Norway, Portugal, and Brazil have followed her example. The submarine type, pure and simple, is undergoing modification and approaching the submersible. The Electric Boat Company, which has built, directly or through its licenses, the greatest number of submarines, has gone over in its new type, M, to a boat with large reserve buoyancy and a partial double shell.

Increase in displacement does not bring to the submarine a proportionate increase in offensive power. It increases the speed but at the same time causes (1) greater difficulties of evolution, submerged; (2) increase of draft preventing navigation in shallow water and easy passage under enemy ships; (3) too large a turning circle; and (4) too high cost.

Laubeuf concludes that two types of submarine are advisable in the future—the moderate tonnage and speed, coast-guard boat of good seagoing qualities, and the squadron boat of 1000 tons displacement, or more, which should have a minimum speed of 23 knots on the surface and 15 knots submerged. With a speed less than this, submarines will be merely an impediment to a

fleet. The necessary step to the attainment of this speed is the realization of a single motor, powerful, reliable, and light, for both surface and submerged propulsion.

Reference[7] (1915) describes the Laubeuf submarine boat and its development. Laubeuf, the naval architect of Messrs. Schneider & Co., made the departure of fitting to submarines hydroplanes to facilitate diving. These constitute the important difference between the submersible boat and the submarine. In submarines of the ordinary type, buoyancy is comparatively low, the ratio of buoyancy on the surface to the total displacement when submerged being less than 15 per cent. In some submersibles it goes up to 22 per cent., but in the Laubeuf type it reaches 33 per cent. Consequently the last have a greater power of emergence and a higher freeboard on the surface than other types.

Especial attention is paid to the comfort of the crew.

The construction and equipment of the Laubeuf boat are described in some detail, and a table is given showing the dimension characteristics of the various classes. The French flotillas are mostly composed of these boats.

Engineering[8] (1911) outlines the development and performance of the Holland boats built by the Electric Boat Company. The number of vessels of this type in commission in the various nations and the builders working under licenses are given. It is stated that to date not a single disaster has overtaken any one of these boats which was built to the unaltered designs of the Electric Boat Company.

A table is given showing the development in size, speed, and fighting power during the ten years from 1895 to 1911. The characteristics of the "perfected" Holland are given with plans and sections. The interior arrangements, provisions for safety, submergence tests, diving mechanism, etc., are described rather fully. These boats take an angle at diving that never exceeds four or five degrees, and is ordinarily only two to two and one-half degrees. The increase of draft due to diving, in excess of that of even keel submergence, is only three to four inches.

Stability conditions are discussed briefly.

Admiral Sims[9] (1917) stated, at a hearing before the House Naval Committee, that a submarine cannot operate safely in the presence of surface boats of the enemy in less than 60 to 70 feet

of water. All submarines draw about the same amount of water from the keel to the top of the periscope; that is, about 40 feet. The speed under water is eight to ten knots, and the radius 40 to 60 miles. After exhaustion of the batteries the submarine must come to the surface and stay for three to five hours. Hence most of her travelling must be done on the surface. Submerged she must keep moving or else rest on the bottom, and this last is only possible in depths less than 200 feet. When moving submerged she leaves a wake. The result of these characteristics is that a naval force commanding the surface can counteract almost entirely the effectiveness of the submarine.

The method of netting submarines is described.

Rodgers [10] (1916) takes up the military functions and recent performance of the submarine of to-day. He points out that because of its inherent peculiarities it is an arm best used by stealth and in dispersed and solitary action. Defensive measures against it, such as wire nets and counter attack by swift patrol boats, have been very successful. It is primarily a defensive arm for the weak. Its notable feats during the present war were confined to the early days before methods of warding off its attacks had been devised and it has accomplished little or nothing when acting in concert with main fleets.

No submarine, even as large as 1200 or 1500 tons, has room for the powerful machinery necessary to enable her to accompany and coöperate with the present battleship of 20 to 23 knots. Hence the practice of the United States Navy in adhering to a 500-ton boat suitable for coast defence seems logical.

Rodgers summarizes the military peculiarities of the submarine which have limited its effectiveness.

The great percentage of displacement necessarily devoted to the heavy hulls and very heavy machinery installation and storage batteries makes armor impracticable, and reduces speed far below that practicable for surface boats of equal size. Hence its chief defence is submersibility and consequent invisibility. The submarine can see nothing when completely below the surface. She can navigate freely and recharge her storage batteries only when running her oil engines at the surface. The great weight of the storage batteries upon which all submerged cruising must be done limits her to a small radius of action when in that condi-

tion, at most 12 miles at 10 or 12 knots, or 100 miles or less at 5 or 6 knots.

Her chief armament, the torpedo, has a maximum initial velocity of 40 miles per hour over moderate distances, compared with 3000 feet per second for a light-power gun projectile and 60 feet per second for the fastest ship. Thus a 30-knot torpedo, capable of running 10,000 yards, has a chance of hitting a boat approaching at 20 knots at a range of over 16,000 yards, but will stop before reaching a boat withdrawing at the same rate, if fired at a range above 3300 yards.

Lake [5] analyzes the limitations of the present submarine that compel "sinking without warning" if it is to be effectual in commerce destroying. He shows by diagram how, owing to the necessity of firing in line with her axis, at a distance of not more than one-half mile, and against the broadside of the boat attacked, the submarine has only one and one-half minutes for effective action against a 20-knot ship. If fair warning is given there is little chance of halting the ship and considerable of the destruction of the submarine. He believes this drawback can be overcome in boats of the future by increase in speed to something approaching that of ordinary ships, and equipment with torpedo tubes to either broadside. A 15-knot submarine so equipped would have nine minutes in which to deal with a 20-knot ship.

Robinson [11] (1915), managing director of the Lake Torpedo Boat Company, gives a general treatment of the subject of the submarine in warfare, concluding with a detailed explanation of the functions and the sort of tactics advisable for each of the three types of to-day—the harbor defence, the coast defence, and the sea-keeping offensive type.

He goes into each of the principal constituent details of the submarine boat, mentions the difficulty of propeller design for both surface and submerged operation, and points out that the United States designs have been loaded down by overemphasis on safety. This last fact has increased the size and cost and lowered the effectiveness. The 200-foot submergence test is an example. All foreign navies have been content with 40 metres (131 feet), and opinion here is tending toward the adoption of the 150-foot limit.

The present type of submarine, of which the United States

has a considerable number, is from 250 to 550 tons submerged displacement, has a surface speed of 12 to 14 knots, and a radius of action, at nine or ten knots, of 1500 to 4500 miles.

"The sea horizon viewed from a periscope 20 feet above the surface is just 10,000 yards. At this range the horizontal angle, subtended by a 600-foot target, is a little under one degree. When the periscope height is three feet above water the sea horizon is distant 4000 yards, and when one foot exposed it becomes 2200 yards."

"The practical difficulties of finding and then firing at specks on the horizon are so many as to compel the submarine to take advantage of her invisibility and immunity from gun-fire to push the attack to close quarters—2000 yards or less."

The "light condition" signifies that all the water ballast tanks are empty and the cruising bridge is rigged.

In the "awash" condition only those water-ballast tanks are empty which are habitually kept full when running submerged. The fore-and-aft trimming tanks and two smaller tanks, called the auxiliary tank and the adjusting tank, are filled with just enough ballast so that when the main ballast tanks are filled the boat will be immediately ready for running submerged without further adjustment of ballast. The submarine then has practically the same stability and safety as when running "light." A small section of the bridge may be kept up for the lookout, and the conning tower hatch may be kept open and the radio rigged.

In the "submerged" condition the ballast and other tanks are filled so that there still remains a small reserve of buoyancy (0 to 800 pounds) and the boat is all ready for submerged running.

Spear [12] (1915) discusses the submarine of to-day and to-morrow at very great length, classifying them as to types and tabulating the size, armament, etc., of each. He takes up the present stage of development and military status, and deduces the probable future of both. So far as known, there are, in the world to-day, about 350 submarines completed and 200 more building.

The mechanical development during 14 years is shown by a comparison of one of the first successful boats (Type A) with one of recent construction (Type B).

TABLE I.

	Type A, 1900 Feet	Inches	Type B, 1914 Feet	Inches
Length	53	10	230	6
Beam	10	3	21	6
Surface displacement, tons	67		663	
Submerged displacement, tons	75		912	
Horsepower, surface	50		2000	
Speed, surface, knots	6		17	
Horsepower, submerged	50		980	
Speed, submerged, knots	5½		10¾	
Radius action, surface, knots	200		3000	
Number torpedo tubes	1		8	

TABLE II.

	Type A, 1900	Type B, 1914
Horsepower main engines	50	2000
Pounds per horsepower	78	48
Fuel consumption, pounds per horsepower	.74	.50
Horsepower electric motors	50	980
Pounds per horsepower	57	48
Pounds per horsepower of storage battery	909	216

Type B is fairly representative of the best results achieved here to date, and the following comparison with boats of other navies corroborates its representative nature:

TABLE III.

	Type B Feet	Inches	English E Feet	German U-21-32 Feet	German U-33-42 Feet
Length	230	6	175	213	223
Surface displacement, tons	663		730	640	665
Submerged displacement, tons	912		825	787	822
Engines	Diesel		Diesel	Diesel	Diesel
Horsepower, surface	2000		1600	1800	2300
Speed, surface, knots	17		15–16	16	17
Speed, submerged, knots	10¾		9–10	10	10
Armament, torpedo tubes	8		6*	4*	5*
Armament, guns	0		2	2	2

* Doubtful.

Considering only boats in active commission and of tried qualities the submarine of to-day has about the following characteristics:

Surface displacement	650 to 750 tons
Submerged displacement	800 to 900 tons
Surface horsepower	1600 to 2300 tons
Surface speed	15 to 17 knots
Submerged speed	9–11 knots
Armament	2 guns of from 3 to 4 inches calibre and 4 to 8 torpedo tubes.

Experience in the Dardanelles, Baltic and North Seas has demonstrated the wide radius of action and efficiency, when operating submerged, of these boats.

The building of modern submarines of smaller surface displacements than 650 to 750 tons is due to military and financial needs and not to engineering limitations. During the last four years boats ranging from 35 to 1100 tons have been laid down.

Above 800 tons these are properly submarines of the future. The smaller ones of those remaining may be explained by certain military and cost considerations. For defensive purposes the only armament is the torpedo, and the main advantage is the submerged condition. Also there is advantage in increasing the number of units. Increasing displacement improves surface qualities more than submerged, or armament, and, because of greater cost, decreases the number of units available. Recent construction programs appear to confirm the opinion that the smallest types are suitable for coast and harbor defence. The characteristics of the *harbor-defence* type are as follows:

TABLE IV.

	Feet	Inches
Length	66	10
Surface displacement, tons	35	
Submerged displacement, tons	43	
Engines	Diesel	
Horsepower, surface	50	
Speed, surface, knots	8	
Speed, submerged, knots	6	
Radius, surface, knots	150	
Radius, submerged, knots	18	
Armament, torpedo tubes	2	

For *limited coast lines*, such as those of Denmark and Holland, larger units, such as the following designs, have been adopted:

TABLE V.

	Design 1 Feet	Design 2 Feet	Design 3 Feet
Length	98	119	116
Surface displacement, tons	132	165	187
Submerged displacement, tons	149	204	229
Horsepower, surface	300	450	350
Speed, surface, knots	11	12	11.5
Radius, surface, knots	1000	1000	750
Speed, submerged, knots	8.5	8	8.5
Corresponding radius, knots	25	24	25
Armament, torpedo tubes	2	2	3

Where there are *long coast lines* or scattered possessions, and financial considerations are not too pressing, vessels of surface displacement of from 350 to 550 tons are now used. The characteristics of some of the best known are as follows:

TABLE VI.

	U. S. K Class	English D Class	French Pluviose	German Brumaire
Length, feet	153	150		
Surface displacement, tons	389	550	400	400
Submerged displacement, tons	519	615	550	550
Engines	Diesel	Diesel	Steam	Diesel
Horsepower, surface	900	1200		850
Speed, surface	14	14	12.3	13
Speed, submerged	10.5	8–9(?)	8	9
Armament, torpedo tubes (internal)	4	3	1	1
Exterior launching apparatus			6	6

The *offensive submarine* is exemplified in its highest development by boats of 650 to 750 tons surface displacement, whose characteristics are given in Table III.

Spear [12] feels that the *harbor-defence* type will not be perpetuated, but the *coast-defence* and *offensive* types will be built in large and increasing numbers. He outlines the military factors affecting future development, and reasons out that the limiting conditions will be:

Submerged speed not less than 10 to 12 knots.

Torpedo tubes not less than four.

Time required to submerge not more than three minutes.

These can all be obtained to-day with a good design of about 250 tons surface displacement. With this list as the minimum the additional factors should be: Submerged radius at least 100 miles at five knots, which will not raise minimum displacement above 250 tons, and will permit of surface speed of 11 to 12 knots and a radius of 1000 miles.

The influence of the engine is shown by an example from actual practice where, with a surface displacement of 350 tons, a trial speed of 14½ knots was obtained with a light two-cycle engine (weighing 56 pounds per horsepower) of 450 horsepower at 450 revolutions. Replacement with heavier engines (86 pounds per horsepower) operating at 375 revolutions per minute reduced the speed to 13 knots.

At present the largest defence boats ordered by the United States are 500 tons surface displacement and 14 knots. Seakeeping qualities place the minimum surface displacement at about 350 tons. A large number of submarines of this size have successfully crossed the Atlantic under their own power.

Spear gives the characteristics of three possible types of boats fulfilling the condition of a 2500-mile effective cruising radius at 11 knots.

Laubeuf [13] (1914) outlines the general tendency of the development of submarines, illustrating with specific boats. He points out that offensive power increases at only a fraction of the rate of increase of tonnage. He believes future development will be in two directions: toward (1) a boat of moderate displacement (400 tons), easy to handle, well armed, and with a small radius of action for coast defence, and (2) fleet submarines of, say, 1200 tons and 22 to 23 knots on the surface, 15 knots submerged, powerfully armed, and with a wide radius of action.

The article is of interest because of the author's illustration of his points by mention of actual boats in service.

Nimitz [14] (1912) considers the facilities of the submarine in respect to communication, mobility, invulnerability, and offensive strength, and the military importance of each.

Besides all usual visual methods, present practice gives a wireless radius up to 50 miles. This could be increased with high masts. For submerged communication, bells are used, and signals have been sent, under the best conditions, eight miles and,

under the worst, one-half mile. No reliable radio method has yet been devised. The invulnerability depends wholly upon invisibility. The offensive strength lies in the ability to fire from near at hand before detection.

The submersible and submarine are compared as to advantages and disadvantages. Possibilities of tactics and military methods are described.

Reference [15] (1916) gives a summary of the performance of submarines during the war up to October, 1916, pointing out their failure to come up to expectations, either in combating larger battleships or in preventing transport of troops to France. The Imperial German Chancellor, in speaking before the Federal Council on August 9, 1916, stated that without sinking at sight submarines could not maintain blockade, and also, that Germany could not build submarines rapidly enough to make up her losses. The article gives 19 as the number of submarines known, more or less definitely, to have been sunk in 1915. The article concludes that, while the submarine has much to its credit, it cannot and is not meant to compete with the surface ship.

Bernay [16] (1912), in discussing French boats, states that the submarine devotes from 35 to 45 per cent. of its displacement to propelling machinery and 20 to 30 per cent. of the displacement to the submerged propulsive machinery. The low submerged speed is, tactically, the weakest point in the submarine. It has been increased from 6 to 7 knots to 10 or 12 in the latest types by improvements in the storage batteries, which seem, however, to have about reached their limit. This increase in speed has necessitated a more substantial periscope standard, in order to avoid excessive vibration, and this makes it more easily seen. Submerged equilibrium, trim, etc., are more difficult to maintain.

The surface speed has been increased with the same tonnage (400) from 12.5 knots in 1905 on the *Pluviose* with steam engines to 15 knots in 1912 on the *Faraday* with oil engines.

The *Gustave-Zede* (1910) and *Nereide* (1911) reached 740 tons surface displacement, an increase demanded for increased speed. England built in 1912 an 800-ton boat simply to get 16 knots, and the Germans are doing likewise.

Lecointe [17] (1911) considers the advantages of the design of submarine designated as the system "del Proposto" and characterized by the use of compressed air instead of storage

batteries for submerged propulsion. The air is stored under high pressure. Submerged it operates, first a compressed-air motor, which may be the compressor reversed, if need be, and after expansion is drawn into an interior combustion engine. A part may be used for ventilation.

The system uses a Diesel engine, as most efficient both in fuel and air consumption. The weight of the compression flasks is reduced by use of high-grade material, such as nickel steel, and by winding with wire, to 4 kilogrammes per kilogramme of air. It is claimed that the weight of air containers per E. P. H. hour is between 16 and 24 kilogrammes, or one-third to one-half that of a very light storage battery. The weight of the latter per horsepower-hour on the propeller is given as about 40 to 50 kilogrammes. The volume per E. P. H. is given as 66 dm^3 to 80 dm^3. The volume of the air containers for a pressure of 250 kilogrammes is not more than 18 to 20 dm^3 per E. P. H. hour.

In approaching an enemy the Diesel engine would be cut out and the boat run by compressed air exhausting into the boat, thus avoiding all gas escape. Considerable distances could be transversed at three to four knots before the pressure rose above three atmospheres.

The inventor claims the boat would be much improved in ventilation, buoyancy, speed of submerging, safety of navigation, etc. Laurenti has worked out the details of design of such a submarine, and gives the weights of the various parts. He gives the radius on the surface as 1450 miles at 16.5 knots, and, submerged, 27.6 miles at 14.60 (maximum 16.6) knots, or 39 miles (*milles*) at 10.3 knots. Without escape of gas the latter would be 18.7 miles at 3.6 knots.

The author claims that a boat of 1000 tons displacement, with a combined battery of compressed-air tanks and Diesel motors weighing 17 kilogrammes per E. H. P., would have the following characteristics:

Maximum surface speed.....	20 knots
Maximum submerged speed	23.2 knots
Radius of action, submerged, at maximum speed	34 miles

It is stated that the German marine has acquired rights (March, 1911) to the invention.

Apparently no experimental trials had been made. Considerable more detail is given in the original.

Reference [18] (1911) gives practically the same material as [17] in a slightly different form.

Daubin [19] (1916) discusses the possible functions of a large, swift submarine, capable of acting in concert with a fleet. The present-day foreign boat of 800 tons, with a surface speed of 15 to 17 knots and the ability to remain at sea for three weeks, is fairly efficient as a commerce destroyer, a guerilla of the sea, or for second-line defence. But geological and military reasons would prevent such boats from being of great value to the United States. Daubin believes that a large, high-speed boat, 18 to 20 knots, with a submerged speed of at least 14 knots and a submerged radius of 30 hours at lower speed, equipped with long-range torpedoes in broadside tubes, and with guns, would offer very great advantages and should be at least attempted. He considers that there is only one quality in which it would be experimental, and that is the speed. He believes such boats could be built in 14 to 20 months, if rushed, and answers the various objections which have been advanced. He believes steam propulsion will be necessary.

Klein [20] (1912) classifies submarines as single and double hull. The first is the original type exemplified by the Holland boat, and used for all the English and Japanese, and almost all of the American boats. The second type is exemplified by the Laubeuf, Krupp, Laurenti, and Lake boats. All German and the greater number of French and Italian submarines are built on it.

Klein [20] compares the two types, mathematically, in regard to (1) stability, (2) seaworthiness, (3) diving qualities, (4) water resistance, (5) resistance to collision.

His conclusions are as follows:

1. The metacentric height in the diving position is better for the single hull. In the swimming position it is too small for the single hull and too great for the double-hull boat. It has been proved that the double-hull boat must have a very great reserve displacement and an excessively great metacentric height in the swimming state in order to get a serviceable metacentric height in the diving condition. This chief objection to the double-hull

boat has been considerably lessened in boats carrying liquid fuel by doing away with the "indifferent" water ballast.

2. The behavior is alike in regard to freeboard, distribution of weight, and reserve displacement. Because of greater reserve displacement the seaworthiness of the double-hull boat is considerably better. Yet it is impossible to get as large a reserve displacement with the single hull.

3. The single hull has an advantage in filling and emptying the ballast tanks. In regard to "dynamic" diving and diving on a level keel, the action of both is similar. For the dynamic method while under water the conditions are equally favorable.

4. In the swimming condition the two-hull boat, and in the diving the single-hull boat, has poorer resistance. Recently the single-hull boats have been built in a form similar to the torpedo boat, and therefore, now, with similar limitation of other characteristics, as good resistance conditions in the swimming condition can be obtained with the two-hull boat.

5. The two-hull boat is better protected against slight collisions. The author's and the Laurenti type of boats has special protection against deck collision. For heavy collisions the only protection is water-tight compartments, and the possibilities for subdivision are the same for both.

American Boats.—Reference [21] (1917) states that the largest American submarine afloat to-day is not over 16 knots, total brake horsepower 1200, while in 1913 Italy accepted four of 18 knots surface and 14 knots submerged speed, total brake horsepower 1500 each. Vickers has built for England nearly 100 submarines of the E-class, and is building 17 more. This class has a speed of 17 to 18 knots.

Reference [22] (1917) states that probably the largest submarine ever built in the United States has completed her trials. The Fore River Shipbuilding Company built her under contract for the Electric Boat Company for the Spanish Government. Her surface speed is 15.36 knots, 1.36 knots better than any American submarine in commission. She is 196 feet long, with a beam of 18¼ feet, a displacement of 700 tons, and a complement of 24 officers and crew. Her cruising radius is 8000 miles. Her engines are the Nlesco.

Bids [23] (1917) has been received by the Navy Department for 34 seagoing submarines of the 800-ton type. The Electric

Boat Company proposed to build 18 within 16 to 26 months at $1,524,000 on the Atlantic or $1,592,000 on the Pacific coast, each. The California Shipbuilding Company and the Lake Torpedo Boat Company would build from four to eight boats each in 24 to 32 months at prices from $1,288,000 to $1,299,000.

Reference [24] (1913) describes briefly a submarine built by the L. A. Submarine Boat Company, Long Beach, Calif., after designs by J. M. Cage, using gasoline engines for both surface and submerged propulsion and with propellers at the bow. The engines are two 90-horsepower, running 900 r.p.m. at full speed, and the boat has an estimated surface speed of 19 knots. It carries compressed air enough to run the engines at full speed for four hours.

Reference [25] (1912) gives the dimensions of the United States submarines E-1 and E-2, launched in 1911 by the Electric Boat Company, New London, Conn. These are:

Length	135 feet 3 inches
Breadth	14 feet 11⅝ inches
Draft cruising	12 feet
Surface displacement	284 tons
Submerged displacement	367 tons
Armament, torpedo tubes	4

A number of photographs are shown.

It is stated [26] (1916) that the United States naval program includes an appropriation of $250,000 for a submarine equipped with the Neff system of propulsion, which eliminates the storage batteries and uses the same source of power for both surface and submerged cruising. The propellers are located at the bow. Large quantities of air for ventilation and combustion are carried in high-pressure air flasks.

The Neff system is the product of the L. A. Submarine Boat Company, Long Beach, Calif., and worked very satisfactorily in 1913 on a 75-foot model.

German Boats.—Treitel [27] (1916) gives the principal characteristics of German submarines under construction as follows:

Displacement submerged	5000 tons
Length	126 metres
Power, surface	18,000 horsepower
Speed, surface	26 knots
Cruising radius	18,000 to 20,000 miles
Speed, submerged	16 knots

Armament:	
Torpedo tubes	30
Total torpedoes	90
Mines	125 to 150
Guns, of medium calibre.	
Guns of small, on anti-aircraft mounts.	
Reënterable turrents and conning tower.	

These dimensions, etc., would call for a displacement of 2500 tons and a storage for 600 tons of oil.

The latest German boats which have had their trials have the following characteristics:

Displacement	2400 tons
Length (over all)	85 metres
Beam	8 metres
Height, excluding conning tower	6 metres
Speed, surface	22 knots
Power, surface	7000 horsepower
Speed, submerged	14 knots
Cruising radius	6500 miles
Armament:	
Torpedo tubes	8 to 10
Guns, small and medium	4 to 8
Supplies for six weeks.	
Crew, 50 to 60.	

Laubeuf [28] (1915) discusses the German submarine and the rôle it has played in this war. He states that, as well as is known, the Germans had, in 1914, 24 submarines in service and 14 under construction, of which last eight have probably been completed since. She also seized six other boats under construction for foreign navies, making her total 38, of which the oldest was launched in 1905. A table is given, showing the characteristics of these boats.

In 1907, when France had 85 submarines, Germany had none. She profited by the extended experience and experimentation of France before beginning construction. Her building plan would have given her 72 boats by 1917. Austria had, at the outbreak of war, six submarines in service and four under construction.

Laubeuf discusses the military functions of the submarine. They have been successful in preventing bombardment of ports and in forcing the blockading fleet to remain at a long distance. He gives a list of their victims.

The German submarines have all been built by private concerns, the French by the state. The typical construction of the German submarine is briefly described.

Reference [29] (1916) states that the building of the *Deutschland* consumed about five months, the Krupp plant having equipment capable of turning out one vessel of this type each month. The *Deutschland* is 313 feet long, 30-foot beam, with a displacement of about 2000 tons. She requires 32 feet for complete submersion. She can carry 650 tons of cargo. The details of engine construction are contradicted by Palmer,[65] and so are not copied here. Her speed is said to have been as high, at times, as 14 knots on the surface. Only 85 tons of fuel were used on the 16-day voyage to America, leaving enough oil for the return trip.

She was said to be equipped with two microphones for the detection of the approach of other vessels.

A general account of the *Deutschland's* trip is given.

The *Deutschland* covered a total of 4100 miles in 16 days. Other long submarine voyages have been those of the German U-51 in 1915, 3,282 miles from Wilhelmshaven, Germany, to the Dardanelles in 42 days; 14 Canadian-built, American-designed boats in 1915, from Quebec to Plymouth, under escort; 4 K-type American boats in 1915, 2100 miles from Seattle to Honolulu in 11 days; English E-14, from Devonport to the Dardanelles; English E-14, 46 days to the Mediterranean.

Austrian Boats.—Reference [30] (1917) says that at the outbreak of the war the Austrian submarine navy consisted of only six boats, all launched in 1908–09. Six others were under construction, some of which afterward succeeded in reaching the Adriatic. The boats had the following characteristics:

No.	Type	Built	Time to Submerge	Submerged displacement	Speed surface	Knots submerged
2	Lake	Pola Arsenal	2¼ minutes	270 tons	12	7.3
2		Germania Yard, Kiel	15 seconds			
2	Holland	Whitehead Works, Fiume		270 tons		
6		Germania Yard, Kiel		1000 tons	18	

Some German boats were shipped by rail, of which one, a mine layer, was raised after having been sunk, and restored by the Italians. She was evidently hastily built, of crude construction, small size and low speed, and carried no armament beyond a dismountable machine gun.

Reference [31] (1914) describes the recent addition to the Austro-Hungarian Navy of the U-III and the U-IV, built at Germania Yard, Kiel, by Krupp. They are 142 feet long, 12 feet 4 inches beam, and have a surface displacement of 235 tons. The general construction is described.

Surface propulsion is by means of two two-cycle heavy oil engines with a total of 600 horsepower. Submerged the boat uses two electric motors designed to develop 320 horsepower. The surface speed is 12 knots, and submerged 8.6 knots. At 10 knots the radius is 1200 miles on the surface or 60 miles submerged, the latter at six knots. The boat can be brought to the surface in one and one-half minutes. The armament consists of two eight-inch Whitehead torpedo tubes.

British Boats.—Reference [32] (1917) copies from the *New York Sun* the report of the recent successful trial of a 21-knot, 5000-i.h.p., steam turbine-driven British submarine.

Reference [33] (1913) describes the English submarine navy, which is stated to be larger than any other. Each type is briefly described and the history of the boats included in it given.

French Boats.—Reference [34] (1911) describes the manœuvres of the French flotilla in 1909–10, and gives the conclusions reached as to the qualities of each of the types of boats engaged.

Reference [35] (1914) states that there were in France, under construction and projected for 1914, 25 submarines, as follows:

No.	Type	Surface displacement	Length meters	Beam meters	Depth meters	Speed knots	Engine
10	*Chlorinde*	410	54	5.1	3.3	15	Diesel
2	*Zede*	797	74	6.0	3.7	20	Diesel
3	Qu-102	520	60.6	5.4	3.7	17	Diesel
8	Qu-105	833	75.	6.4	3.99	19	Steam
2	Qu-107	630	68	5.5	3.75	17	Diesel

Dutch Boats.—Reference [36] (1914) describes with detailed drawings the construction of a Dutch submarine. She is 48.58 metres over all, 4.32 metres beam, and has a surface displacement of 328.8 tons. She has two eight-cylinder, double-acting, reversible Diesel engines of 850 i.h.p. at 450 r.p.m., of the Augsburg type, giving a maximum speed of 16 knots for three hours and a cruising speed of 11 knots.

For submerged running the storage batteries of 3830 ampère-hours for 5 hours, or 4400 ampère-hours for 10 hours, will give

11 knots maximum cruising speed for one hour, or eight knots for four hours.

A submarine bell and receiving instrument are installed. The armament consists of two torpedo tubes at the bow and one at the stern for 45-cm. Whitehead torpedoes. There are two periscopes.

Engineering[37] (1912) describes briefly the tests of a submersible recently completed on the plans of Whitehead & Co., Fiume, by Koninklyke Maatschappy "de Schelde," at Flushing, for the Dutch Navy. The following special points are mentioned: Pumps capable of pumping against a head of 200 feet; a static driving gear by means of which, and at small expense of power, an exact regulation (within 1 dcm.) of the desired depth is possible; two periscopes 6 metres long; turning diameters of 180 metres on the surface and 160 metres submerged; extreme habitability, with accommodations for 11 men for one week. The boat is 105 feet long, with 10-foot beam. Her 300-horsepower Diesel engine and electric motor give her a surface speed of 11.2 knots and a maximum submerged speed of 11 knots. Her radius of action on the surface is 1000 miles at 10 knots, and submerged 6 hours 23 minutes at seven knots, or 1 hour at 11 knots.

Miscellaneous Boats.—Reference[38] (1909) is an unsigned article describing the development and present status of the submarines of the different navies. The policy and progress of experimentation in the various countries is outlined and the results critically examined. A list is given of the submarines in commission, building, and projected, with the type, year of building, motive power, horsepower, displacement, dimensions, velocity, radius, and torpedo tubes of each.

Weaver[39] (1911) describes in great detail the cruise of the submarine *Salmon* from Quincy, Mass., to Bermuda and back in 1910.

The *Salmon*, like practically all United States submarines in service, was of the modified spindle form instead of the ship form of the Lake, Laurenti, Laubeuf, and Krupp type. The cruise demonstrated that this single-hull type has, (1) for a given power of machinery, a higher submerged velocity, and (2) higher structural strength for diving in deep water. These advantages are gained at the cost of habitability and seaworthiness.

The *Salmon* was 40.097 metres long over all, 4.232 metres beam, total displacement submerged of 337 tons, and was equipped with gasoline engines. She carried 22 persons. The full log is given and shows the behavior of the submarine in heavy weather. It was concluded that in storm a submarine is safer than any other type of boat, but it is very uncomfortable in heavy weather.

Reference [40] (1916) gives photographs and a brief description of the German mine-laying submarine C-5, which was 110 feet long and 10 feet maximum diameter. She carried 17 men and one officer, was driven by two-cylinder Diesel engines, and had a surface speed of about six knots.

Bieg [41] (1915) suggests the possibility that an offensive submarine might be very serviceable in combating the operations of a fleet against our shores, and outlines the characteristics of a type which he would like to see tried out.

His boat is a heavily armored ship with hull designed for the greatest efficiency for surface running. She would not dive, and would submerge only to the awash condition, and merely to make herself invisible while out of range. Within range she would depend upon her armor, and the illusiveness of so low a target as well as fighting within a range so short that it would be hard to reach with the big guns.

Musoforiti [42] (1917) has invented a device for automatically raising a sunken submarine by inflation of collapsed, air-tight bags with acetylene generated by the action of water on calcium carbide.

Skerrett [43] (1912) describes a combined salvage and testing dock for submarines, launched by the Italian Government.

Reference [44] (1911) describes a French submarine salvage boat, giving the dimensions. She is without motive power.

Reference [45] (1914) describes the Italian submarine salvage vessel *Anteo*, which is designed to follow the fleet during manœuvres or in time of war. She is propelled by two compound engines of 800 horsepower. She is 165 feet long and 78 feet broad, and has equipment for raising 400 tons from a depth of over 200 feet at a rate of over four feet per minute.

Reference [46] (1912) describes the submarine transporting ship *Kanguroo*. This boat is so designed that a part of the bow may be removed and the submarine floated directly into the hold, which is 193 feet long.

Dantin [47] (1916) describes the Brazilian submarine depot motorship *Ceara*. This ship has facilities for lifting and dry-docking the submarines attached to it, as well as accommodations for their crews, supplies, etc. She is 328 feet long, 51 feet broad, with a displacement of 4130 tons and a speed of 14 knots. Her equipment is described very fully. Particular attention is paid to her Diesel engines.

Davis [48] (1916) gives very fully the constructional details and general layout and equipment of the United States submarine tender *Bushnell*, with tables of dimensions and diagrams.

References [49] (1914–15) give in detail the dimensions, equipment, and tests of the submarine tender *Fulton*. The second of the references is the more detailed, but does not cover the trial tests.

Motorship [50] (1917) gives much detail and discussion of submarine chasers and patrol boats, and of the Diesel engines used in them. Builders are given.

Lake [5] (1915–16) discusses the advantages and practicability of a special type of submarine for navigation under ice, as in polar exploration. He also suggests its use in locating and gathering shellfish from the bottom of the ocean. He has already designed a special type for the purpose.

Dietze [51] (1911) deals mathematically at some length with the physics and hydraulics of the submarine, methods of diving, and changes in buoyancy.

Klein [52] (1913) gives a mathematical investigation of the principles of dynamics underlying the operation of submarines, under the headings of "Equilibrium Conditions," "Stability," "Determination of the Magnitude, Direction, and Position of Water Resistance by Means of Models."

He gives a bibliography of technical articles on the submarine from 1859 to 1911, which he states is as complete as possible.

Werner [53] (1914) discusses the stability of submarines while filling the ballast tanks, and deduces mathematically the conditions that must be fulfilled for safety, and their translation into proper design of boat.

Reference [54] (1916) describes the deep submergence test, at 200 feet depth, of the Lake type boat G-3. The pressure at this depth is 88 pounds per square inch, and the boat was subjected to it for 14 minutes.

II. PROPULSION.

Engines.—Berling [55] (1916) describes in considerable detail the general equipment used for propulsion in submarines. He gives the combined weight per horsepower of all the propulsive machinery of a submarine as about eleven times that for the modern torpedo boat. On account of the greater pressures the hull of the former must have 20 per cent. greater weight, and of the total building weight only 28 to 30 per cent. can be allowed for machinery, compared with 48 to 50 per cent. for the latter. These facts explain the limited speed of the submarine.

The Diesel engines consume about 190 to 220 grammes (0.42 to 0.485 pound of fuel per horsepower hour.

Berling shows mathematically that any increase in the weight of surface propulsion machinery must cause a decrease in submerged speed, and *vice versa*. By a comparative table, computed from data of tank-model towing experiments, propulsive coefficient measurements, and British Admiralty formulæ, he proves that the oil-electric boat of moderate size has reached the upper limit of propulsive effect.

Steam was early used for surface propulsion, but maintenance of bearable temperatures within the submarine demands, with it, the use of extensive cooling and ventilating apparatus. The steam engine, besides occupying more space, also consumes about 3.5 times as much oil per horsepower as the Diesel engine, and so makes it impossible to obtain more than 15 knots surface speed without reducing the radius of action considerably, a tendency which is increased by the crowding of the living spaces.

Berling describes very fully the operation of the steam soda-boiler power plant of the German inventor Hönigmann, with illustrations and arrangement of a proposed submarine of 700 tons fitted with the system.

With this system, surface cruising is done with a steam engine. At the same time part of the steam is used to concentrate a sodium hydroxide solution. When submerged, low-pressure steam heats this solution and is absorbed by it. The latent heats of condensation and of solution of the sodium hydroxide produce enough further heat to generate steam in a flask surrounding the soda container for running the engines.

No exact details of such engines have reached the public since 1885, but the author gives what he regards as probable figures.

Evaporation of the sodium hydroxide takes one and one-half hours when the boat is at rest and three to four when under way, compared with a minimum of six to ten hours for charging storage batteries. The oil consumption is about 2.8 times as much per horsepower as with the oil-electric drive. A 3000-horsepower soda boiler capacity should take about three tons of oil for renewal and then be capable of from one and one-quarter to one and one-half hours at 12½ knots submerged. The weight for the submerged installation is very much lower than for any other type. The life of the soda boiler is rather limited and the space requirements are high. A table of computed weight of machinery, speed, radius, etc., for each of eight different displacements is given.

(See also Berggeen,[63] ii, p. 286.)

Berling also outlines the "Del Proposto" system, using either compressed air or oxygen to supply the internal-combustion engines during submerged cruising. He states that one pound of fuel oil requires about 24 pounds of air for combustion. He illustrates the arrangement by diagram. The machinery parts are designed so light as to allow very little factor of safety. The result is a boat of only 435 tons displacement, capable of 1400 sea miles awash at 16.45 knots and 27.6 miles submerged at 16.6 knots. (See Lecointe[17] (1911), i, p. 96, and Berggeen[63] (1916), ii, p. 264.)

Berling considers what he calls a rational boat construction of sufficient armament, convenient living spaces, diving rudders, etc., and analyzes, the results from the installation of the above-mentioned different types of machinery. He tabulates the weight and space occupied by each type of installation, and the capacity, speed, and radius of the resulting boat. He gives comments and data of actual tests on the combinations listed. He shows by curves (1) weight requirements for submerged machinery installation with increasing capacity, (2) space requirements for submerged machinery installation with increasing capacity, (3) resistance curves for submarine and for submersible, on surface and submerged.

Berling concludes with the statement that the capacity limit of submarines will always be low so long as two fundamentally different types of machinery must be used for propulsion. Past failures have been due, first to the weight of the hull, and second,

to the fact that, with single motors for both surface and submerged running, the oxygen, which must be carried in flasks, very considerably increases the weight and space requirements.

The article gives a good idea of how closely balanced and interrelated are the requirements and limitations of space and machinery, weight and speed.

Reference [56] (1916) is the original of [16] and is illustrated with many photographs as well as diagrams. The former are omitted from the translation.

Hoar [57] (1916) considers that the present-day submarine dates from the adoption of the internal-combustion engine as a source of power. There is a tendency, however, at the present time to return to steam.

The gasoline engine was first used and was installed in the A, B, C, D, and three of the G class of our navy. It gave very satisfactory operation, and, in view of its recent perfection, could now be expected to do even better. It was light, compact, and simple. The drawbacks are cost of fuel, danger of fire, explosion, and asphyxiation or poisoning by the escape of carbon dioxide or monoxide gas. Of these the author considers only the first real and insurmountable.

The Diesel engine, which was next adopted, burns almost any low-grade oil which can be vaporized, and it develops 1 brake horsepower per hour from 0.55 to 0.63 pound of fuel. The theory of its operation is simple and is given in brief for both the two-cycle and four-cycle types. The economy of the former is much lower than the latter.

In practice the engine is far from simple, as the excessive temperatures, going as high as 3000° F., together with the high cylinder pressure (500 to 900 pounds per square inch), impose demands hard to meet.

The ideal submarine engine should be of high power and speed, light, simple, and accessible. Reliability and accessibility have to be sacrificed at present in order to make the Diesel engine meet the other requirements, and simplicity is little likely ever to be attained with it. The engines in service give a great deal of trouble, and the author believes that the relative success of the German boats in this war has been due to their working in relays and being given a thorough overhauling after each cruise.

The recent increase in size of submarine, demanding an

increase in engine power which the Diesel cannot meet, together with the weight and space limitations, and the increased efficiency and reliability of the steam engine, have led to a certain reversion to the latter.

It is now possible with the oil-burning boiler to get an efficiency as high as 0.7 to 0.8 pound of fuel per brake horsepower. The weight is much less and the simplicity and accessibility much greater than for the Diesel motor. The mean effective pressure in the steam unit is higher, and the maximum cylinder pressure is about one-quarter that in the Diesel engine. The extreme temperature is less than a fourth.

The ideal propulsion would be a single power plant for surface and submerged running. Hoar mentions the "Del Proposto" and soda-boiler schemes. He accredits the last to D'Equevilley, a Spanish engineer, but states that the principle is old, having been used in this country by Luck in 1873. The system has also been tried in Germany and France, etc., but it is not believed that any great success has been attained.

The L. A. Submarine Boat Company, of California, with which Hoar is connected, has recently perfected a system using the same unit for surface and submerged propulsion, but details are not yet available for publication. This is mentioned in reference [19] (see part I).

Bernay [16] (1912) states that a French submarine built in 1902, designed to operate submerged on oil engines supplied by compressed air, was a failure. Two others designed to operate in closed cycle with oxygen were never finished. He states that an Italian firm is actually building a boat on the "Del Proposto" system.

Chalkley [58] (1915) mentions the fact that the submarine in its present form owes its existence to the internal-combustion engine. Gasoline was used at first, and several such engines are still doing good service.

The first Diesel submarine engine was completed in 1907 or 1908, and this engine was adopted practically at the same time by British, French, and German navies. Difficulty was encountered from the first in the necessity for increasing the speed of rotation in order to get a minimum weight of machinery. The high temperature of combustion, 1200 to 1500° C., led to further difficulties.

The weight of the slow-running Diesel engine used on mercantile vessels is about 350 pounds per brake horsepower, against 50 to 70 pounds for the submarine engine.

The author discusses the types of engines, two-cycle, four-cycle, etc., used by the different navies, and gives descriptions of the manner of operation and illustrations of the Krupp, Nürnberg, Sulzer, and Polar.

He concludes by pointing out that the development of the submarine is limited only by the peculiarities of the engine. Much larger and faster (20 knots or more) boats will be built just as soon as satisfactory motors of 2000 or 3000 brake horsepower are produced.

The internal-combustion engine is ideal for the submarine, in that it can be started or stopped instantly, permitting rapid submergence and emergence.

Lake[5] outlines the transition from one type of gasoline engine to another, and finally to the Diesel engine, and the troubles encountered. He believes that the demand for increased speed in the last years has come so rapidly that reliability has been sacrificed. Bearing pressures have been run up to 1700 pounds per square inch, and complication of construction has increased tremendously. He was present at a test of a reversible, continental engine running at 450 revolutions per minute on a small boat, and the noise was such that conversation without shouting was only possible on deck near the bow. A photograph is given.

This engine works very well at 100 revolutions per minute, but when run up to the 350 to 400 revolutions per minute necessary to get the required horsepower into the limited space available in a submarine the noise is terrific.

The Diesel engine of 500 pounds or more per horsepower works satisfactorily on land, but the attempt to change to a reversible high-speed engine of 50 pounds per horsepower has brought great trouble. Millions have been expended without yet producing a satisfactory result.

"There are some destructive actions in connection with large, high-speed, light-weight internal-combustion engines that practically all designing engineers have failed to grasp. Otherwise engineers of all nationalities would not have failed to the extent they have, and I do not believe there is a submarine engine in

service to-day that has fully met the expectations of its designers and builders. It is unfortunate for the engineering profession that government policy will not permit of a full disclosure of the defects of engines and other equipment in government-owned vessels. Were a frank disclosure made other inventors and engineers would, in all probability, take up the problems, and they might then sooner be solved."

Lake concludes from his experience that, in the successful heavy oil engine which will eventually be produced, bearing pressures should not exceed 1000 pounds per square inch of projected area on main bearings or crank-pins. For some as yet undiscovered reason, the diameters of crank-shafts must be increased from the five-inch, which are more than ample to transmit 600 horsepower at 400 revolutions per minute on the steam engine, to at least seven inches for the same service on the Diesel submarine engine. Lake gives specific instances where disregard of this point has brought failure in operation. He states that the recognition by our government of the need for greater reliability is shown by the fact that the latest requirements eliminate the reversible engine, so that reversing, even on the surface, must be done on the electric motors. While this is a step backward, it will give the engine builders a very necessary chance to catch up.

Photographs are given of the latest model of the Krupp six-cylinder, two-cycle engine, of which a large number were under construction just before the war; of the Fiat-San Giorgo six-cylinder, two-cycle engine, designed for 1300 brake horsepower at 350 revolutions per minute, which is the largest submarine engine yet built of which Lake has any knowledge; of the Augsburg four-cylinder, four-cycle engine, which is used and has given good service on a number of German submarines, in spite of its greater bulk and weight, because of its fuel economy and reliability; and of the Sulzer engine, used on some of the Lake and European boats. The last type is built in Switzerland and also by the Busch-Sulzer Brothers-Diesel Engine Company, at St. Louis, Mo., in "one of the most complete plants of the kind in the world."

The 1300-horsepower Fiat engine mentioned above as probably the largest submarine engine built to date had sucessful shop tests. Its subsequent history is not known. As the 25-knot sub-

marines authorized by Congress (in 1914) must be at least 300 feet long and have not less than 10,000-horsepower to meet that speed requirement, the advance in engine development required is very considerable.

Bedell[1] (1917) states that the Nürnberg type of Diesel engine was the one chosen to succeed the gasoline engine for surface propulsion, and many are still in operation. The type has been much modified in recent American submarines, and the resulting engine has given good service. The heavy oil now used gives twice the number of horsepower-hours that can be obtained from the same volume of gasoline. Bedell gives no exact data.

The offensive (Spear[12]) (1915) or fleet submarine demands high surface speed, and this depends upon the surface power plant. The maximum power per unit of Diesel engine in actual service is about 1200 horsepower, but larger units are under construction.

Germany uses many four-cycle engines, but more commonly two-cycle, of very high speed and light weight.

England has almost wholly four-cycle engines of moderate speed and weight.

France and Russia use both types of greater weight and moderate speed. The tendency in the United States is toward a heavier engine of moderate speed, though a number of the fast, light-weight, two-cycle type have been installed.

The Diesel engines employed vary from 50 pounds per brake horsepower and 500 revolutions per minute to 100 pounds per brake horsepower and 350 revolutions per minute. A fair average is 70 pounds.

At present it is entirely practicable to install from 4000 to 5000 horsepower in a boat of 900 to 1100 tons surface displacement. With this displacement and a length of 260 feet the above power will give 20 or 21 knots. For 25 knots, if the length be restricted to 300 feet, excessive length being very undesirable, and with a displacement of 1200 tons on the surface, from 10,000 to 12,000 horsepower would be required.

Such a speed requirement may force the use of the steam engine, temporarily, in spite of its serious disadvantages, and with constant sacrifice of submerged qualities, all very serious defects from a military standpoint. France at present uses steam on a few of her submarines. Adaptation for the 25-knot sub-

marine might easily prove a failure, and would be but a temporary expedient at best.

Discussion brought out several further points. The fact that the power plant for a 25-knot boat is a problem still unsolved was emphasized. High surface speed means sacrificed submerged speed, and *vice versa*.

The possibility of increasing the efficiency of the Diesel engine by increasing the oxygen content of the cylinder charge was discussed.

Lisle[59] (1917), in an article discussing in detail the "Submarine Diesel-Type Engines of the World's Navies," accredits Germany's successes in commerce destruction to her command of the Diesel engine. The various engines and their modes of operation are described with so great detail and so many illustrations, as well as numerical data, that full abstracting is not feasible.

Germany.—The majority of the German submarine engines have been built by Krupps and by the Augsburg Works of the Maschinenfabrik-Augsburg-Nürnberg. The Krupps had developed their two-cycle engine, with its special phosphor-bronze cylinders, crankcases, and cylinder heads, up to 900 to 1000 brake horsepower on a weight of 18 tons by the latter part of 1910, while in 1917 the largest Diesel engine in a completed American submarine is only 600 brake horsepower (1200 brake horsepower for a twin-screw boat). It is not improbable that the engines of the latest German submarines are 2000 brake horsepower each, or 4000 brake horsepower per boat, giving the larger boats of the U-class a speed of 20 to 31 knots. Of late the Krupps are devoting their attention to the four-cycle type, and are thus able to revert to cast-iron construction.

The first set of the Nürnberg two-cycle engines of 900 brake horsepower at 450 revolutions per minute was completed early in 1913, but was not so successful as the Krupp and Augsburg engines.

The Augsburg four-cycle engine is one of the most successful in the German Navy. It has a considerable overload capacity.

Germany has ordered engines from the F. I. A. T. Company.

Great Britain.—Submarine construction is wholly in the hands of Vickers, Ltd., and only of late has any information been available. The 1912 class were said to be 1200 tons, re-

quiring two Diesel engines of about 1200 brake horsepower each. The latest engines give about 4000 brake horsepower per boat in 24 cylinders.

Reference [32] (1917) copies from the *New York Sun* the report of the recent successful trial of a 21-knot, 5000-indicated horsepower, steam turbine-driven British submarine.

Great Britain has also ten small submarines recently built by the Fore River Shipbuilding Company and engined by the New London Ship and Engine Company.

France.[59]—France first used gasoline power, then steam, later Diesel engines, then steam again, and now both steam and Diesel motors. She was the first to use the Diesel engine in submarines, and has had exceptional experience with many types. She has two submarines of about 5000 indicated horsepower in service. One (the Gustave Zede) is a 1000-ton steam turbine boat fitted with eight torpedo tubes. She is swift, but her cruising radius is only 2300 miles, or about half that of the modern Diesel-engined submarine.

The other is a Diesel-driven boat of 1700 tons, of a total indicated horsepower of 6000 or 4800 brake horsepower, which should give 20 knots. This is probably the highest-powered Diesel-driven submarine in the world, and should be the ideal fleet submarine sought by the United States.

Schneider & Co., who build these engines, give the following results of a series of tests made in 1914 on eight-cylinder reversible models:

TESTS OF SCHNEIDER-DIESEL ENGINES.

	Two-cycle	Four-cycle
Power developed	1121 b.h.p.	360 h.p.
R. P. M.	404.6	400
Fuel-oil per brake horsepower hour	240.7 gr. (9.2 oz.)	218.5 gr. (7.5 oz.)
Lubricating oil per effective horsepower hour	8 gr. (0.2 oz.)	8.8 gr. (0.3 oz.)

The Normand engines use tar oils, mineral oils, and vegetable oils.

The Sabathé engines employ combustion at constant volume and at constant pressure. The four-cycle type has a fuel consumption of 178 g. (6.10 oz.) of Russian residual oil per brake horsepower at the normal running speed of 400 revolutions per minute, a remarkably economical record.

France has also used Nürnberg, Krupp, Augsburg, and Sulzer Diesels.

Holland.—The design of the engines turned out by the Werkspoor Company is characterized by several radical departures from ordinary practice.

Japan.—Japan's submarines, so far as known, are installed with Schneider, Sulzer, Vickers, Krupp, Thornycroft, and F. I. A. T. engines, all of the Diesel type, except the eight Thornycroft sets supplied ten years ago, which are eight-cylinder, four-cycle, gasoline-kerosene motors, developing 350 brake horsepower on kerosene and 400 brake horsepower on gasoline, two engines to a boat.

The highest-powered foreign Diesel engines used are 16-cylinder Schneider sets of 1100 brake horsepower per engine. (See *Motorship*, December, 1916.)

Italy.—When the war broke out the F.I.A.T. Company had just completed a pair of engines of 1300 brake horsepower each for a Laurenti type of 700-ton boat. They must have given the boat 20 to 22 knots. These were intended for Germany.

Russia.—In 1913 designs were drawn for a very large seagoing submarine of 5400 tons displacement, 430 feet length, and 38 feet beam. She was to have two Nobel-Diesel engines, each of 9000 indicated horsepower, and a surface speed of 26 knots. Her armament was to be 30 torpedo tubes and five 14-cm. quick-firing guns. The author doubts whether her keel was ever laid. Russia has bought of M. A. N. and of Krupps.

United States.—The United States, largely because of lack of competition, has not reached the stage in the development of the submarine already attained by France, Germany, England, and Italy, four or five years ago. The largest boat under construction is the Schley, 1100 tons surface displacement (1500 tons submerged), to have four 100-brake horsepower Nlseco-Diesel engines giving a surface speed of 20 knots.

Shaw [60] (1917) describes a Danish submarine engine built by Burmeister and Wain and not mentioned in the article by Lisle. It is four-cycle, with six cylinders of 13-inch bore and stroke, and rated at 450 brake horsepower at 500 revolutions per minute. The length is 14 feet 6 inches and height 6 feet 2 inches. It weighs 19,800 pounds, or about 44 pounds per brake horsepower. Tests in competition with a slightly larger

two-cycle German engine of the same power showed a fuel saving of 18 per cent. at full power and 24 per cent. at 10 knots.

[61] (1917) As an appendix to Lisle's paper [25] *Motorship* gives the following table:

SUBMARINE ENGINES OF THE WORLD AT A GLANCE.

Name	Country	Cycles	B.H.P.	Cylinders	Bore, inches	Stroke, inches	R. P. M.	Weight, tons	Weight per B.H.P.	Piston speed per minute, feet	Horsepower per cylinder
Augsburg	Germany	4	900	6	15.7	15.7	450	.....	.....	1177.5	150
Busch-Sulzer	U. S. A.	2	600	6	12.2	11.8	400	.....	.....	786.6	100
Craig	U. S. A.	4	300	6	12.5	15.0	300	.....	.....	750.0	50
F. I. A. T.	Italy	2	1300	6	.....	.....	400	25	43	.....	217
Krupp	Germany	2	1000	6	13.7	13.7	425	18	40½	1112.1	166
Loire	France	4	420	6	.....	.....	400	.....	.....	.....	70
Nlseco	U. S. A.	4	600	8	.....	.....	450	.....	.....	.....	75
Nobel	Russia	4	180	6	8.8	11.8	500	2	30	983.3	30
Nobel	Russia	4	1200	6	.....	.....	400	.....	.....	.....	200
Normand	France	4	420	6	13.0	14.2	400	18.5	99	946.6	70
Nürnberg	Germany	2	900	8	12.0	13.3	450	.....	.....	997.5	112
Polar	Sweden	4	350	6	11.4	11.75	300	16.75	172	587.5	70
Sabathé	France	4	500	6	13.75	13.75	400	14.75	60	916.6	83
Sabathé	France	2	700	8	12.25	15.75	310	22.5	72	813.7	87
Sabathé	France	2	500	6	12.25	15.75	310	14.75	66	813.7	82
Schneider	France	2	2400	8	18.5	.....	.....	.....	.....	.....	300
Schneider	France	2	1100	8	13.0	14.5	400	.....	.....	966.6	138
Schneider	France	4	360	8	12.0	11.0	400	.....	.....	733.3	45
Southwark-Harris	U. S. A.	2	550	6	12.0	14.0	375	19.5	80	875.0	91
Sulzer	Switzerland	2	600	6	12.2	11.8	400	.....	.....	786.6	100
Vickers	England	4	1800	12	.....	.....	400	.....	.....	.....	150
Werkspoor	Holland	4	550	6	.....	.....	450	12	49	.....	91
Werkspoor	Holland	4	450	6	14.2	14.2	400	11	61	946.6	75
Werkspoor	Holland	4	240	..	.....	.....	450	4.5	42	.....	.....

Nimitz [62] (1916) describes in considerable detail the three types of submarine engines built by the Germans just before the war. Their principal characteristics are as follows:

Name	Weight per b. h. p.	Cycles	B. h. p. at	r. p. m	Cylinders	Cylinder bore	Stroke
Augsburg	.. 51 lb.	4	1000	450	6	310-mm.	420-mm.
Nürnberg	.. 46	2	850–1050	450	8	310-mm.	340-mm.
Krupp	.. 45	2	900	450	6		

All are single acting. The Augsburg on full load consumes about 200 g. or 0.44 pound of fuel per brake horsepower. Augsburg and Krupp types are directly reversible by compressed air. The Krupp engine is built almost entirely of bronze, except for cast-iron cylinders and pistons and crank-shafts, connecting rods, wrist-pins, and valves of steel. The Nürnberg housing is of cast bronze, but the Augsburg engine is of iron and steel.

It is probable that the power of the Augsburg and Krupp engines has recently been increased by adding two more working cylinders. This would give the former at least 1350 brake horsepower on each shaft of a submarine. The Krupp engine power

could be increased similarly, but its length would then be excessive. Nimitz gives considerable further detail as to the arrangement, etc., of these engines.

The modern submarine is usually driven by twin screws, and for surface propulsion depends on Diesel engines, one or more on each shaft. Germany's long experience with this type of engine has given her the lead in the construction of submarine engines, and upon this has rested her success in the submarine service.

A reliable engine is the heart of the submarine problem. Upon it rests the endurance of the crew and the whole success of the boat. No perfection of other details can compensate defects there. This surface motive power is also the weakest point in the submarine. Increase in size and tonnage and in the demand for higher speeds has complicated the matter further, and the last, particularly, has led to many failures of engines and hence of submarines. This factor has been at the root of the apparent failures of American submarines.

The endurance of the submarine is measured by four things: endurance of the main engines, fuel and lubricating oil supply, storage battery water supply, and endurance of the crew, of which the first and last come back to the reliability of the engine.

The engine is also the determining factor in the time necessary for building a submarine.

Berggeen [63] (1916) mentions briefly the soda boiler, accrediting it to d'Equevilley, a French engineer, and states that it is bulky and that its centre of gravity is high, but that the principle seems the best yet proposed. He also mentions briefly the characteristics of the Nürnberg, Fiat, Sulzer, and Polar-Diesel submarine engines.

Lisle [64] (1916) describes in detail the design of the Craig-Diesel four-cycle engine for submarines. This has been installed, so far, only in a modified form in two boats in which it was necessary to replace Vickers engines. Great claims are made for the type.

Palmer [65] (1916) discusses the type of Diesel motors installed on the *Deutschland*. H. Kleis, chief engineer of the boat, told the author, "The *Deutschland* is fitted with two six-cylinder, four-cycle Krupp motors developing 600 brake horsepower each at 380 revolutions." They are smaller than the regular Krupp

submarine engine, which develops from 1200 to 1500 brake horsepower per unit at 500 revolutions. The motors are of steel and iron instead of the special Krupp bronze construction. Steel is used in the cylinder head and crank-case, and the cylinders are, as usual, of cast iron, with removable linings of the same metal. Krupp has retained bronze construction in the two-cycle motor, but no longer uses it in the four-cycle. The *Deutschland's* engines performed admirably, with absolutely no cracked pistons nor cylinder trouble. The longest non-stop run was 245 hours, and on the first round trip the engines turned over 11,000,000 times. Kleis gave further cylinder and stroke dimensions, but these are doubted by Palmer as inconsistent with the accredited horsepower, etc.

J. L. Bogert, in commenting on Palmer's article, states that the standard German submarine is believed to be 800 tons displacement (the *Deutschland* is not less than 2000, according to the cargo she carries) and capable of 17 knots an hour under the "full power impulse of her Krupp 850-brake horsepower, twin six-cylinder Diesel engines." From this he deduces the probable cylinder dimensions of the *Deutschland*.

Wentworth [66] (1916) presents for criticism and as a basis for further work the design (in 14 plates) of a light, reliable engine suitable for submarines, giving data and substantiating reasons for the special points involved. His engine, for which full data and drawings are given, is four-cycle, which he regards as superior because of the greater variability in speed possible, greater simplicity, and at least one-tenth higher efficiency. It fulfils the following conditions:

	Feet	Inches
B. H. P. per engine	450	
Revolutions	450	
Length over all not to exceed	14	9
Width not to exceed	3	8
Height above centre of shaft not to exceed	6	0
Distance below		23
Weight not to exceed	26,000 lb.	

The specific points of the design and the factors affecting each are discussed in detail, with particular reference to reversing, fuel and fuel feed, starting, compression, cylinder temperature, speed variation, fuels. Comparisons with ordinary practice are given.

Robinson[11] (1915) outlines the principle of operation of the Diesel engine, quoting from Milton (*British Institute of Naval Architects,* April, 1914).

Storage Batteries.—Berling[55] (1916) states that the modern lead storage battery has a life of about 400 charges, which means for the average submarine, making practice runs, a life of from five to six years. The most recent, with a 3½-hour discharge rate, weigh about 35.5 kg. (78.3 pounds) per horsepower hour delivered. The electric motors, including all wiring and control apparatus, weigh about 60 kg. (132.5 pounds) per horsepower hour at the same rate of discharge, or the total weight for the electric propulsion is 214 kg. (472 pounds) per horsepower hour.

He gives a table comparing capacity and other characteristics of the lead and Edison batteries.

Arnold's[67] (1912) article is a repetition and extension of a publication by Bezzi and Bartoli in the *Revista Marittima* for January, 1912, on the use of electricity in submarines.

The reasons for adopting accumulators for submerged propulsion are discussed.

The power of various batteries is shown by tables:

Type of submarine	Displacement, tons	Power of motors, horsepower	Power of battery, kilowatts	Capacity of batteries, kilowatt-hours
Hoalen (Swedish)	250	220	180	540
Velella (Italian)	300	300	246	738
Trasher (United States) ..	450	415	340	1020
Mariotte (French)	1000	800	650	1950

The types of batteries are compared as follows:

Type	Per kilowatt-hour on three-hour discharge: Weight, kilogrammes	Volume, cu. dcm.	Price, marks	Discharges before wearing out
I. Lead, positive Planté plate	73.5	37	156	250
II. Lead, positive pasted plate	62.0	24	160	200
III. Same of greater capacity ..	56.0	19	152	150
IV. Iron-nickel, Edison	42.0	18	270	400
V. Same, Jugner	43.0	20	270	400

This makes the cost for average kilowatt-hour in marks:

I.	0.62
II.	0.80
III.	1.01
IV.	0.68
V.	0.68

The voltage generally used now is 110 or 220, though voltages of 440 have been employed in the past.

The precautions of insulation and ventilation necessary to safety are mentioned.

The characteristics of operation and advantages of the lead and Edison batteries are compared graphically and otherwise.

The motors serve as generators in charging the batteries. The points of importance in their choice and method of regulation are discussed rather fully.

Hoar [57] (1916) describes the make-up and nature of the plates used in submarine storage batteries. Only lead batteries have been employed up to the present time. The three forms used are the Planté, pasted plate, and ironclad plate.

One or two boats have been recently fitted with Edison batteries.

The lead battery is objectionable because of its weight, nearly 59 tons, the space which it occupies, and the poisonous and explosive gases it generates, and because of the acid electrolyte, which is liable to slopping over and will then attack the hull.

The Edison battery avoids only the danger of chlorine gas and leaking acid. At the three-hour rate of discharge it gives only 1.1 to 1.2 volts, compared with 1.83 volts for the lead battery, and consequently the number of cells used must be 60 per cent. greater. The weight is higher also. The Edison battery is more costly, but has a much longer life than the lead battery.

Robinson [11] (1915) gives very much the same data as Hoar,[57] describing the make-up of the plates used in the storage batteries. The voltage of the lead battery at the three-hour rate of discharge is about 1.84 volts, compared with 1.2 volts for the Edison. Hence for the same average total voltage, 192 of the latter cells should be required in place of 120 of the former. The Edison battery is the more bulky and heavy for the same power. The life is longer, though a nearly equal life is now claimed for the ironclad battery, but the cost is far greater.

Lake [5] barely mentions the batteries. He states that two types, the Planté all-lead, and another with pasted lead plates, are employed in submarines. Both use sulphuric acid and require ventilation during charging, as does also the recently announced Edison submarine battery. The last is said not to give off chlo-

rine or any other poisonous gas when salt water gets into the batteries, an accident that has caused the loss of some lives in the past. Diagrams are given of the casing and ventilating cover.

III. ARMAMENT.

Torpedoes.—The effectiveness of the Whitehead torpedo and the difficulties to which it is subject are mentioned at some length by Biles[68] (1914). In the Russo-Japanese War only 5½ per cent. were effective hits, and no ship was sunk immediately by a single torpedo. There were only 2 per cent. effective hits on *moving* ships.

The torpedo is a very close range weapon and should be used within 400 yards. Speed is the battleship's best defence.

Special forms of armor are suggested. But fleets of small rapid boats are suggested as the most effective protection.

Dumas[69] (1915) describes in detail, with 13 illustrations, the mechanism and use of the Whitehead automobile torpedo, introducing his paper by a brief history.

He points out that the torpedo is peculiarly the weapon of the submarine because of the latter's ability to get within the very short range (800 to 900 metres) necessary, before detection. Although most of the battleships destroyed in this war have been sunk by torpedoes, yet at the battle of Heligoland many torpedoes were launched by both German and English ships without any of them taking effect.

The first Whitehead torpedoes were 356 millimetres in diameter, 4.42 metres long, weighed 272.9 kilogrammes, and carried a charge of 18 kilogrammes of gun-cotton. Their range was 400 metres at 20 knots or 37 kilometres per hour. Modern torpedoes are generally 0.450 metres in diameter, as long as 6.6 metres, weigh 70 kilogrammes, and carry a charge of 100 kilogrammes. Their range is 1000 metres at 43 knots or 8000 to 9000 metres at 28 knots. Some navies use torpedoes of 500 and 533 millimetres diameter, carrying 150 kilogrammes or even more of explosive.

The Whitehead torpedo, in its various modifications, is the one almost exclusively employed, although the United States Navy also uses the Howell torpedo.

The arrangement and operation of the Whitehead torpedo are given in considerable detail. It is propelled by compressed air.

under 85 to 150 kilogrammes, whose temperature during expansion is maintained by the burning of gasoline. Excessive temperatures are prevented by the injection of a spray of water. Further details are given in the original. The motor is of the Brotherhood type and has four cylinders.

The regulating and directing devices, propellor, stabilizing gyroscope, etc., are fully described.

The torpedo generally runs at a depth of 3 metres, but can be regulated for much smaller depths. The Germans have used one running at less than 1.60 metres.

The launching tube is shown and its operation explained.

Michelson[70] (1913) describes and shows the construction and operation of the Whitehead torpedo, which, he states, is used internationally. The charges of explosive now used are from 120 to 150 kilogrammes. Picric acid and trinitrotoluene are the most commonly used.

The English 55.3-cm. torpedo will run 10,000 to 11,000 yards. Its effective range is probably only 6000 metres. The motive power is compressed air. Gasoline can be used, but is apparently not advantageous. The article gives details of construction and of progress in efficiency since the early types.

The depth variation in the course of the torpedo is very slight —only a few centimetres—but its sidewise variation is about one per cent. of the distance run.

The Davis torpedo differs only in its head, which is such as to cause the force of the explosion to be expended within the hull of the vessel attacked. It follows in its course the line of the tube from which it is fired.

Modern French submarines already carry seven tubes.

In the discussion it was brought out that torpedoes similar to the Whitehead are manufactured by Schwartzkopff in Germany, and the German marine has also developed a slightly different and much improved type.

The gyroscope and heating apparatus are especially important to further development.

Reference[71] (1913) gives a detailed description, of the mechanism, method of operation, method of firing, and use of the torpedo. The air heater is described. Pictures are shown of parts, etc., of the Whitehead, Schneider, and Woolwich types of torpedoes. The article is a good condensed statement.

Heinz [72] (1909) goes into great detail over the heating of the propelling air in the automobile torpedo. He gives the history of this development, with details of its application, cuts of apparatus, etc., in different systems, and comparison of the resulting efficiencies of the torpedo.

Bernotti [73] (1913) solves mathematically the problem of aiming torpedoes both for single and broadside firing.

Pramer [74] (1914) treats of the torpedo and its use in war in an article of 146 pages, illustrated with diagrams. He points out in the beginning that, because of its recent and extremely rapid development, the effectiveness of the torpedo has never been thoroughly tested. All practicable tests outside of actual warfare are entirely inadequate. Recent improvements, particularly in regard to range, velocity, steering, and weight of explosive charge, have been very great.

He then describes the status of the arm in the summer of 1913. It is impossible to review the different types of torpedoes. Each navy keeps its own construction, the outcome of experience, secret. Published data are very scanty.

The Whitehead torpedo made at Fiume, was operated by unheated compressed air at an initial pressure of 150 atmospheres. It was of 45 centimetres calibre, 2¼ metres length, carried 90 to 100 kilogrammes of explosive, and had a maximum range of 3000 metres at a velocity of about 23 to 24 nautical miles per hour at a depth of three metres. For 1000 metres it had a velocity of 34 miles per hour. Heating the propelling air increased the range to 1500 metres at 40 miles per hour, or 6000 metres at 28 miles per hour. This improvement in the propulsion made possible an increase of calibre. England and Germany increased to 53 centimetres and France to 60 centimetres.

The modern English Hardcastle torpedo, which was brought out about two years ago, is another advance, whose improvement is made possible by increase in length. Its range is 9000 metres at 30 nautical miles per hour, or 1000 metres at 45 miles per hour, and it carries 130 kilogrammes of explosive. It is reported that the most recent modification of this torpedo has a range of 9900 metres at 30 to 40 miles and carries 150 kilogrammes of explosive.

The German product has already attained, in the 60-cm. torpedo of nine metres length, a sufficient speed for 12,000 metres,

and for 100-metre runs at 52 nautical miles per hour. The heating device has been improved, probably by addition of an oxygen cartridge, so that the fuel is fully utilized.

The American 53-cm. torpedo with a hot-air turbine drive should give great economy at high speed, but is not reported to be very satisfactory. It stands far below the English and German. It carries 145 kilogrammes of explosive and has a velocity of 40 nautical miles for 1500 metres, 30 miles for 4000 metres, and 25 miles for 5000 metres.

Of torpedoes with explosion-motor drive, the technical press reports that Japan has one of 60-cm. calibre, with a gasoline motor and a range of 12,000 (?) metres at about 30 nautical miles per hour.

The torpedoes of the French marine, like the Whitehead torpedo, have ranges of 1000, 2000, and 3000 metres at 40, 34, and 29 nautical miles respectively. The straying of the Whitehead was less, being 0.6 per cent. at 1000 metres, 0.75 per cent. at 2000 metres, and 0.83 per cent. at 3000 metres, against 1 per cent. of the distance passed over for the French torpedo.

The French use two types, one for long range with light machinery, large air flask, and not very high speed, the other for high speed. The first goes 8000 metres at 28 to 30 nautical miles per hour.

England and Germany use one type, with the highest speed possible with high explosive charge.

The Davis torpedo, an American type, is designed to break its way through protecting nets by means of the explosion of a small charge, without affecting the main charge of explosive.

The use of the gyroscope marked a great improvement in the torpedo. Without it constancy of direction could be obtained for about three minutes, sufficient for the range of the torpedo, without heating apparatus or steam injection, at a velocity of 25 nautical miles per hour. With range extended to 5000 metres a better direction regulator became necessary.

A seven-minute constancy is necessary for 6000 metres at 30 miles. For torpedoes of over 6000 metres range the English and German navies use an electrically-driven directing apparatus.

Recently a new gyroscope has made possible launching from a tube at an angle with the course of the torpedo. It makes possible the use of fixed tubes placed to good advantage in the boat.

The explosive mostly used is wet gun-cotton, as this has the most favorable properties in regard to lack of sensitiveness toward jar and temperature change, stability, etc.

Forty-five-centimetre torpedoes take 93 kilogrammes and 53-cm. 113.5 kilogrammes of explosive.

The modern torpedo explodes, whatever the angle at which it hits its target.

The latest Whitehead torpedoes had in the spring of 1913 the following characteristics:

Calibre, centimetres	Range, metres		Speed, nautical miles per hour	Lateral deviation at fixed target, metres	Maximum range, metres
45	1500	at	40		
	6000	at	27		
53	3000	at	38	20	
	5000	at	31	50	7000
45	2000	at	44.6 }	(Two-cylinder motor)	
	6000	at	30.3 }		

The total deviation at 2000 metres was about half the length of a modern ship going at a speed of 18 nautical miles per hour. In hot-air torpedoes a velocity variation of 1.5 nautical miles was tolerated, or, including the lateral deviation, a total of about two nautical miles per hour. A torpedo with a velocity of 40 miles goes about 2000 metres in about 100 seconds. A variation of two miles per hour equals a variation of 100 metres in the time that a boat travelling at 18 nautical miles would move 45 metres. This makes the extreme range under these conditions 2000 metres when all is favorable.

Pramer goes into the details of the methods of using the torpedo as a weapon in war, at very great length. (He considers the principles and mathematics of range finding and aiming, and illustrates with many diagrams.) His chapters are headed:

II. Launching in General Without Consideration of Tactical factors.

III. The Target.

IV. The Torpedo Carrier.

V. Short-range Use.

VI. Long-range Use.

Reference [75] (1912) describes with illustrations the Davis torpedo. This includes, within the limits of an 18-inch 5-metre torpedo, a gun of 8-inch calibre, firing an explosive shell of 215 pounds with an increase in weight slightly less than an augmented charge of gun-cotton. This projectile has a muzzle velocity of 1000 foot-seconds. It is capable of penetrating 4- or 5-inch armor plate of hardened steel. So far as known, the bulkhead defence against torpedoes of none of the battleships built to date is thicker than 1.77 inches, and the average is 1.5 inches.

Vergnier [76] (1911) describes the construction and testing of the three types of Schneider torpedo which are used by the French Navy. In addition to the usual details, he mentions that the temperature in the cylinders of the motor does not exceed 200° since the injection of water has been employed.

The testing station at Hyères is described in detail.

Gray [77] (1914) gives the fundamental mechanics underlying the behavior of the gyroscope, and simple illustrations of its action when applied to various devices.

Gray [78] (1914) gives the simple principles for the application of the gyrostat to controls for torpedoes, submarines, etc. He analyzes the forces involved and gives graphic illustrations, and mentions the possibility of further use in very high speed, long-distance torpedoes.

Biles [68] suggests the possibility of protecting battleships from submarine attack by armor plate four inches thick on the bottom. This would reduce the speed about two knots. In the discussion a number of points are brought out.

Guns.—Schiffbau [79] (1913) states that the Krupp light gun equipment consists of the 3.7-cm. gun with total weight of 265 kilogrammes. The heavy equipment consists of a 7.5-cm. gun with a total weight of 860 kilogrammes. Both are so mounted that they can be closed down into the space between the deck and the hull. They require the service of two or three men each. Details of mounting are given. The guns are made of high-percentage nickel-steel to resist corrosion, since the compartment is not water tight.

Reference [80] (1914) describes with illustrations the two types of Krupp guns carried on submarines—the disappearing

and the permanently mounted. The latter must be small (37 mm.) to avoid high resistance. Both are made of non-rusting nickel-steel. The larger gun is a short, powerful 12-pounder of 75-mm. calibre, capable of sinking a torpedo boat, and it can be fired vertically at an airship. This gun can be raised and fired in 20 seconds.

Bernay [16] (1912) states that the recent 800-ton German and English submarines are provided with 88- and 75-mm. guns respectively.

IV. SPECIAL EQUIPMENT.

Periscope.—Lake [5] (1915–16) mentions briefly the characteristics of the periscope, and says that the instrument giving normal image and a correct idea of distance dates from 1900. He intends to describe in a later article a device which he believes can be used at night when the present instrument is useless. He states that periscopes are now so made that the heavens as well as the horizon may be viewed.

Weidert [81] (1914) takes up at great length the construction and development of the periscope. The year 1906 brought such improvements in this instrument, as well as in other details of the submarine, that a great many of the previously insurmountable obstacles were overcome. Extensions of the field of vision, sharpness and brightness of the image, ease of observation, and the development of means of measuring the distance, marked that year. Mechanical improvements, such as the extending and withdrawing of the periscope, have followed. While all the early patents originated outside Germany, the modern construction is almost wholly covered by that country's patents.

The author reviews and describes the patents and developments from the earliest forms down to the complicated instruments of the present, with their many optical improvements and attachments. The material is too detailed and specific to abstract, and is also well illustrated.

Reference [82] (1916) describes the recently patented Parodi periscope.

Submarine Signalling.—Fay [83] (1917) describes the work of the Submarine Signal Company in developing means for signalling under water. Bells were used at first for the signalling in-

strument, and the signals were received by microphones installed in tanks filled with water, mounted on the ship's plates, one on each side of the boat. The microphone on each side was connected to a separate telephone receiver, so that comparison of the intensities served to give the direction of the sound received. In this form the apparatus was ideal as a fog signal, and was used to some extent for sending messages.

Introduction of the Fessenden oscillator has now produced a great advance, as it is more powerful and more rapid, and serves as both transmitter and receiver of signals. This oscillator is similar in principle to the telephone receiver, but magnified about 200 times. The diaphragm, 24 inches in diameter and several inches thick, is placed in contact with the water, to which it transmits its vibrations just as the telephone diaphragm does to air. The greater amount of energy required to make so heavy a diaphragm vibrate is supplied by a powerful electromagnet. The field magnets employed are energized by a direct current of 7.5 ampères and the diaphragm is set in motion by a current of 11 ampères at 180 volts on the windings of the core. The details of construction are given in full with a cut.

The oscillator operates at a frequency of 540 cycles per second. In receiving it is also affected by outside noises from waves, etc. Its maximum range of signalling is about 30 miles, and the average 5 to 10 miles. Signals are frequently sent at 20 words per minute.

The dimensions of the oscillator are about 30 × 16 inches, and its weight is about 1200 pounds. It is used in pairs, similarly to the microphone, and in submarines is placed in the forward ballast tanks, one on each side, low enough down so that signals can be sent and received when on the surface.

On ships the best position varies, but is about 15 feet below the water-line and not too near the keel. The microphones must also be near enough to the bow so that they face slightly forward.

At present the face of the diaphragm is so mounted as to form a part of the skin of the ship. The method of accomplishing this is shown by diagram, and cuts are given of the electrical apparatus required.

Perkins[84] (1914) gives a general review of the subject of submarine signalling by means of gasoline, electric, pneumatic,

and hand devices, with cuts. It is claimed that these methods of signalling can be used to guide ships into harbor, to enable fishing dories to return to their ships, to enable submarines to manœuvre in flotilla, to make navigation in fogs safe, etc. The United States submarine *Octopus* was saved from collision with a towline, while running a submerged test, by such a signal from her tender.

Signals by bells are said to have been heard 27 miles. Such bells are used for guiding ships in fogs in the English Channel, and Irish and North seas. The signals are given by bells hung on tripods at the bottom of the sea and rung electrically from shore. Buoys with bells rung by the wave motion are used similarly.

The receiving apparatus for such signals consists of microphones attached to telephone receivers. The microphones, arranged in pairs, one on either side of the ship, are immersed in tanks containing water. These tanks are 16 × 16 inches or 18 × 12 inches on the surface, and are attached two-thirds of the distance from the water-line to the keel. Pneumatic and electric bells are used for signalling. The sound passes through the skin of the ship to the water in the microphone tank, which is not in direct communication with the outside water. The sounds from port and starboard microphones are transmitted separately to the pilot, who by comparing the loudness can swing the boat until the intensities are equal, when it will be headed directly toward the sound. The article is confused in expression and gives considerable trivial detail, such as total weights and overall dimensions of the signalling apparatus, etc., for different purposes.

Carter[85] (1914) gives a brief general account of the method of signalling under water. He speaks of Fessenden's oscillator and Berger's vibrating steel ribbon. He considers the problem as promising, but still in the very primitive stage. The part so far taken by the Submarine Bell Company of Boston is mentioned.

Cathcart[86] (1914) mentions the uncertainty of most forms of signalling during fog, and contrasts the variability of the air as a method of transmitting with the constancy of condition of the water. He says that the bell-signalling outfit of the Submarine Signal Company is now installed on about 1225 ships. The bells send out a sound of about 1200 vibrations per second,

which is distinctive among the low-pitched noises of the ship. He gives Professor Fessenden's own description of his oscillator, with illustrations. At a frequency of 500 per second this delivers 35 kilowatts of mechanical power to the water at an efficiency of over 90 per cent. Signals can be sent by code and have been read at a distance of 30 miles with the receiver a foot from the ear, when using only 10 per cent. of the full power of the oscillator. Preliminary tests on sound reflection from icebergs and from the bottom are mentioned.

Blake [87] (1914) mentions briefly the advantage of submarine signals over other types. Even wireless does not indicate direction. Submarine methods do this, but the bell and microphone method have various objections, such as slow rate, etc. Many of these are overcome by the Fessenden oscillator. This apparatus is described and illustrated. It consists of an electromagnetically vibrated diaphragm weighing over 100 pounds.

It is stated that by use of this oscillator even telephony is possible, sentences having been transmitted 800 yards and conversation carried on at 400 yards with the use of an ordinary telephone with six dry cells. Signals have been heard a distance of 20 miles from a boat running at eight knots.

Other probable uses are the taking of soundings and detection of icebergs by the echo of tones sent out by the oscillator, the elapsed time indicating distances. Successful tests have been made of both of these uses.

Millet [88] (1914) states that the bell and microphone method of submarine signalling worked out by him in the nineties was quickly adopted by all the large transatlantic line companies, and submarine bells are now in operation at nearly 200 points on various coasts. The Fessenden oscillator has opened the way for a great advance, and provides a means of detecting icebergs at distances of one-half to two and one-half miles.

Millet gives a brief mention of earlier investigators of the general problem.

Sawyer [89] gives a similar account of the history and need for submarine signalling. He describes in a very general way experiments made by the United States Navy with the device of the Austrian, Berger, involving the vibrations of a steel wire or strip, and later with the Fessenden oscillator.

V. BUILDERS.

Boat Builders.—Aarestrup[90] (1913) gives the European firms which build or are building submarines, either on their own or licensed designs, as follows:

Firm	Location	Boats built
Electric Boat Company	Central office in Paris	about 165
Germaniawerf (Krupp)	Kiel	35
Fiat-San Giorgio	Spezia	25
Schneider	Creusot	10
Weserwerft	Bremen	1
Denny Brothers	Dumbarton	1

The following companies are also connected with the building of submarines:

England:

Firm	Under license of
Vickers	Electric Boat Company.
Scott	Fiat Company.
Armstrong	Schneider Company.

Italy:

Orlando	For Fiat and license holders of Electric Boat Company.

Holland:

Schelde	Electric Boat Company.

Russia:

Newskywerft	Electric Boat Company.
Nicolaieffwerft, Lessner and Nobel	Plans of Russian engineers.

Sweden:

Bergsund	Swedish Marine Electric Boat Company.
Kockum	Fiat Company.

American:

Fore River Shipbuilding Company.[22]
Electric Boat Company.[22]
California Shipbuilding Company,[22] Long Beach, Calif.
L. A. Submarine Boat Company, Long Beach, Calif.
Snyder & Co. (French),[22] New York City.
International Submarine Shipbuilding Company, Maine.
Lake Torpedo Boat Company,[20, 22] Bridgeport, Conn.

Engine Builders.—The products of most of the following builders are described[59] (1917):

German:
Fried. Krupps, Kiel-Gaarden. Augsburg Works of Maschinenfabrik-Augsburg-Nürnberg. (Körting Bros. and others build moderate powered sets.) Nürnberg Works of M. A. N. (Designs at one time used by New London Ship and Engine Company.)

British:
Vickers, Ltd., Barrow. (Mr. James McKechnie, technical director.)
Scott Shipbuilding Company. (Holds license from F. I. A. T. Company.)

French:
Schneider & Co., La Creusot. (M. Drosne, Chief Engineer.)
Augustin Normand & Co., Havre.
(Sabathé Company.) Société des Moteurs Sabathé, Usines de la Chaleassière, St. Etienne.
Société des Ateliers et Chantiers de la Loire.

Dutch:
Werkspoor Company, Amsterdam.

Danish:
Burmeister and Wain,[88] Copenhagen.

Italian:
Franco Tosi Company, Legnano.
Fiat-San Giorgio, Spezia.
F. I. A. T. Company, Turin.

Swiss:
Sulzer Brothers, Winterthur. (Busch-Sulzer Company, St. Louis, Mo., U. S. A.)

Swedish:
A. B. Diesels Motorer (?) (Polar Engine). (License owned by McIntosh & Seymour Corporation, U. S. A.)

Russian:
Kolomaer Company (?).
Maschinenfabrik Ludwig Nobel, Petrograd.

American:
Snyder & Co. (French),[89] New York City.
New London Ship and Engine Company, Groton, Conn. (Nlesco Engine.)
Busch-Sulzer Company, St. Louis, Mo.
James Craig Engine and Machine Works, Jersey City, N. J.
Southwark Foundry and Machine Company, Philadelphia, Pa. (Southwark-Harris engine.) (License bought by British Admiralty.)
McIntosh & Seymour Corporation, Own Polar license.

Reference[91] (1917) gives the following list of firms in the United States building Diesel engines, and the type produced by each:

DIESEL MARINE ENGINES.

Builders	Type
American Krupp-Diesel Co.	Krupp 4- and 2-cycle.
Atlas Gas Engine Co.	Atlas 4-cycle.
Bethlehem Steel Co.	Bethlehem-West 4-cycle.
Busch-Sulzer Co.	Busch-Sulzer 4- and 2-cycle.
James Craig Engine Works.	Craig 4-cycle.
Wm. Cramp Ship and Engine Co.	Burmeister & Wain 4-cycle.
Fulton Mfg. Co.	Fulton 4-cycle.
Gas Engine and Power Co.	Speedway 2-cycle.
McIntosh & Seymour Corporation.	Polar 4-cycle.
Newport-Weiss Shipbuilding Co.	Werkspoor 4-cycle.
New London Ship and Engine Co.	Nlesco-M. A. N. 2- and 4-cycle.
New York Navy Yard.	Nlesco-M. A. N. 2- and 4-cycle.
New York Shipbuilding Co.	Werkspoor 4-cycle.
Seattle Machine Works.	Seattle.
Seattle-Astoria Iron Works.	Troyer-Fox 2-cycle.
Standard Motor Construction Co.	Standard 4-cycle.
Standard Gas Engine Co.	Southwark-Harris 2-cycle.
Southwark Foundry and Machine Co.	Southwark-Harris 2-cycle.
Union Gas Engine Co.	Craig 4-cycle.
Union Iron Works.	Union & Nlesco 4-cycle.
Winton Engine Co.	Winton 4-cycle.
Wisconsin Motor Mfg. Co.	Wisconsin 4-cycle.

Many of these firms have built no engines as yet, and the list is largely of potential interest.

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[22] See Part I.
[25] See Part I.
[29] See Part II.
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The following books are a few of the most recent treating of the submarine. All are brief and non-technical in character. An exhaustive treatise seems to be lacking, in English at least.

TALBOT, "Submarines": their mechanics and operation. 1915. 264 pp. Van Nostrand Co.

This book, designed for the general reader, is a very good general treatment of the submarine, covering history, mechanism, operation, military functions, armament, etc.

HOAR, "The Submarine Torpedo Boat," its characteristics and modern development. 1916. 204 pp. D. Van Nostrand Co.

This book is a profusely illustrated treatise on the subject designed for the "general reader," as have indeed been practically all the books published on this subject. Hoar has, however, gone into considerable detail, and his book contains much valuable data. Ten pages are devoted to the torpedo.

DOMMETT, "Submarine Vessels," including mines, torpedoes, guns, steering, propelling and navigating apparatus, etc. 1915. 106 pp. London, Whitaker & Co.

This is a very brief and elementary outline of the main characteristics of the submarine which explains quite clearly the details of operation of the various appliances. It is intended for the general reader.

LAUBEUF, "Sous-Marins et Submersibles." 1915. 104 pp. Paris, Librarie de la Grave.

This book is a brief discussion of the salient features of the submarine—its history, types, use in war, future, and an account of the number, dimensions, armament, and speed of the German fleet.

Spontaneous Combustion of Oleic Acid Containing Iron. C. E. SWETT and W. S. HUGHES. (*Journal of Industrial and Engineering Chemistry*, vol. 9, No. 6, p. 623, June, 1917.)—A case of spontaneous combustion of oleic acid when applied to wool was recently observed in a mill. The wool or other hair fibres were first oiled with 10 per cent. of their weight of oleic acid, after which the oiled fibre was conveyed to bins through a tinned iron pipe by a current of air. The conveying pipes were very near a bank of heating pipes employed to heat the mill.

An analysis of the oil showed nothing of suspicious nature, but it was found that the finer fibres gave a greater rise of temperature. This fact was ascribed to more surface for oxidation with the finer fibres. To test this point cotton was tried, and a rapid and dangerous rise was found. As no such rise was found with pure oleic acid of pharmaceutical grade, it was apparent that something about the oleic acid was wrong, notwithstanding the results of the analysis. Briefly, it was found to contain 0.10 per cent. ferric oxide. An oleate of iron was next made and dissolved in the pure oleic acid, so that it contained the same amount of iron as the commercial sample. When this oil was applied to cotton it was found to give the same dangerous rise as the commercial sample. The small amount of iron had functioned as a catalyzer to promote oxidation.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

THE REFLECTING POWER OF TUNGSTEN AND STELLITE.[1]

By W. W. Coblentz and W. B. Emerson.

[ABSTRACT.]

THE reflecting power of tungsten and in the region of the spectrum from 0.5 to 6 μ was determined by comparison with silver, and by a new method employing a total reflection prism. Four samples of tungsten in the form of plane, highly polished mirrors were examined. The reflectivity of tungsten rises abruptly from 50 per cent. at 0.5 μ to 90 per cent. at 2 μ.

All samples of tungsten show sharp indentations at 0.8 μ in the reflectivity curve. A similar indentation occurs at 1.3 μ in the reflectivity curve of the pure metal, but not in an impure sample. The application of these data to the question of increasing the luminous efficiency is discussed.

The reflecting power of stellite rises from 65 per cent. in the visible to 88 per cent. at 9 μ.

STANDARD SAMPLES FOR THERMOMETRIC FIXED POINTS.[2]

[ABSTRACT.]

THIS circular (No. 66) describes the methods of preparation and the chemical analyses of the metals, tin, zinc, aluminum, and copper, which have been prepared by the Bureau of Standards for distribution.

The melting-points of these materials were determined with platinum-resistance thermometers, and will serve to define accurately certain fixed points of the temperature scale so that they may be used for the calibration of pyrometers, the samples distributed being sufficient in amount (about 50 cm.^{3}) for this purpose.

The metals are all of American manufacture and are probably of as high a degree of purity as has been attained in the preparation of relatively large amounts of such materials. The chemi-

* Communicated by the Director.

[1] Scientific Paper No. 308.

[2] Circular No. 66.

cal analyses show purity as follows: Zinc, 99.993 per cent.; tin, 99.988 per cent.; copper, 99.987 per cent.; aluminum, 99.66 per cent.

TESTING OF CLINICAL THERMOMETERS.[3]

[ABSTRACT.]

THE Bureau of Standards has just completed a revision of Circular No. 5 on the "Testing of Clinical Thermometers." This new edition, which is the third so far, announces the adoption of new regulations, effective January 1, 1917, governing the testing of clinical thermometers. Past practice was to issue certificates containing tables of corrections at four points, 96°, 100°, 104°, and 108° F.; the new certificates will be issued only for thermometers correct within 0°.1 F. at normal (98°.6), and 0°.2 at 104°, and will contain the statement that the thermometer is correct within these tolerances.

The circular contains a full description of the method of testing clinical thermometers and considerable matter of general interest concerning these instruments.

The question of accuracy in clinical thermometers is obviously an important one. The clinical thermometer bears the same relation to the physician as the weighing scale does to the merchant, but, in a way, the former is vastly more important, as it has to do with life itself.

It has been estimated that over a million of these little instruments are manufactured each year to replenish the supply, for a clinical thermometer is delicate and usually short lived. Unscrupulous manufacturers, taking advantage of this never-ceasing demand, place on the market thousands of unreliable thermometers which, on account of their cheapness and the fact that their defects are almost impossible of detection, find ready sale.

It is obvious that the Bureau cannot inspect all these thermometers, for it tests only those that are voluntarily submitted. This circular calls attention to the fact that thermometers of doubtful accuracy may always be checked at this Bureau, and that when a thermometer is offered for sale with a Bureau of Standards certificate its reliability cannot be questioned. If instruments of a high quality are thus demanded, in time the unreliable article will no longer be manufactured.

[3] Circular No. 5.

AN ANEROID CALORIMETER FOR SPECIFIC AND LATENT HEATS.[4]

By Nathan S. Osborne.

[ABSTRACT.]

THE unstirred type of calorimeter has been embodied with important refinements in an instrument especially designed for determinations of specific heat and latent heat of refrigerating media. Heat developed and measured electrically is distributed automatically to the calorimeter and contents, whose temperatures are measured by a platinum thermometer. Heat from other sources is excluded by a null method.

The calorimeter is adapted for use between − 50° and + 50° C. in experiments where the measured heat added is used either to change the temperature of the contents or to evaporate a portion of the contents withdrawn as superheated vapor; in the first case the specific heat of the liquid and in the second the latent heat of vaporization being obtained when proper corrections are made.

THE RELATIVE SENSIBILITY OF THE AVERAGE EYE TO LIGHT OF DIFFERENT COLORS, AND SOME PRACTICAL APPLICATIONS TO THE RADIATION PROBLEMS.[5]

By W. W. Coblentz and W. B. Emerson.

[ABSTRACT.]

THIS paper gives data on the relative visibility of radiation of the average eye, based upon a group of 130 observers. The data were obtained by means of a flicker and an equality-of-brightness photometer. The energy evaluation of the light stimulus was made with great care.

The point of maximum visibility of the average eye is at $\lambda = .5576\ \mu$. A mathematical equation is given of the average visibility curve, which is applied in calculating the luminous energy emitted by a black body at various temperatures, and the mechanical equivalent of light. The eye responds to light having an intensity less than 1×10^{-16} watts per cm.^{2} The paper describes tests on diffuse light and on a physical photometer. A screen is described which transmits radiations proportional to the average eye.

[4] Scientific Paper No. 301.
[5] Scientific Paper No. 303.

Curve Plotting with Logarithmic Coördinates. ANON. (*The Electric Journal*, vol. xiv, No. 7, July, 1917, p. 259.)—The advantages of logarithmic cross-section paper have been appreciated for many years by some engineers, but there is room for its more extensive use. Any exponential equation of the general form $y = kx^n$ will be a straight line when plotted on double logarithmic paper. Similarly, any equation of the general form $y = ka^{nx}$ will be a straight line when y is plotted logarithmically and x arithmetically. This characteristic is especially useful in plotting, for example, a series of hyperbolas, which, on arithmetical paper, must be plotted from a number of calculated points, while on logarithmic paper only two points, or only one point and the slope, are necessary.

An advantage of the logarithmic paper, not so widely recognized, is that it gives the same percentage accuracy over its whole range, in the same manner as a slide rule. With straight cross-section paper, if at a value of 15, a quarter of an inch represents a change of ten per cent.; the same distance gives a change of only one per cent. at a value of 150. On logarithmic paper, however, a given distance means the same percentage change on any part of the scale. A correlative advantage is the great foreshortening of the scale. It is practically impossible to plot values over a wide range on arithmetical paper; whereas with logarithmic paper the values between 1 and 2 are just as legible and have the same percentage accuracy as those between 1000 and 2000. Where the foreshortening effect only is desired, it is not necessary that the coördinates be the same scale. The abscissæ scale may be several times that of the ordinates; or they may be uniform, to represent time or other similar intervals.

Still another advantage of the logarithmic paper is that the slope of the line representing an exponential equation is proportional to the exponent. A variant of this advantage is illustrated by the curves in the article by Mr. C. E. Skinner in the JOURNAL OF THE FRANKLIN INSTITUTE for June, 1917. When the slope of a curve changes suddenly, a critical point is generally indicated; that is, a point at which some change in the structure or characteristics of the material being analyzed takes place. Such a change in curvature is difficult to notice on arithmetical coördinate paper or from inspection of the data. But even a slight change in the slope of a straight line is readily noticeable, so that such a critical point is much more apparent when the data are plotted logarithmically.

NOTES FROM THE RESEARCH LABORATORY, EASTMAN KODAK COMPANY.*

PHOTOMICROGRAPHS IN COLOR.[1]

By Dr. C. E. K. Mees.

[ABSTRACT.]

LANTERN slides representing photomicrographs of stained sections should, in order to give satisfaction, closely resemble the appearance of the section itself. This can be attained by making the print in stained gelatine instead of by the usual photographic process.

The process of making such a print is as follows: Lantern plates (Seed or Standard plates are satisfactory) are sensitized by bathing for five minutes in a 2½ per cent. solution of ammonium bichromate containing 5 c.c. of strong ammonia to the litre, the temperature of the bath being not above 65° F. The plates are then rinsed for two or three seconds in clean water, drained, and dried as uniformly as possible, the plates being kept in the dark during drying. The sensitized plates are then exposed through the glass under the negative to the light of an arc lamp, the average exposure being about three minutes at 18 inches distance. Printing cannot be done by daylight, or sharp images will not be obtained. The exposed plates are then developed by rocking in trays of water at about 120° F. until all soluble gelatine is removed. Underexposure is indicated by the high-light detail washing away, and overexposure by the film being insoluble to too great a depth. The plates are then rinsed in cold water, fixed in hypo, and washed free of the hypo. They are then ready for staining.

The staining is done with a one per cent. solution of dye containing one per cent. of acetic acid, the dye being selected to simulate most closely the original stain of the section, the time of dyeing being chosen so that the necessary depth is obtained.

When sections stained with two different colors are being

* Communicated by the Director.

[1] Communication No. 50 from the Research Laboratory of the Eastman Kodak Company, published in *American Photography*, 1917.

photographed negatives are made through suitable color filters and are then dyed in the two stains and placed face to face so that a two-color slide is obtained.

Suppose a section is stained red and green. Two negatives are made on panchromatic plates—one with a red filter, which will cause the green to appear as clear spaces in the negative and will not record the red, and the other with a green filter, which will record the red and not the green. The slides made as described from these in bichromated gelatine are stained—that from the red negative with the original green stain, and that from the green negative with the original red stain.

The filters required can be chosen from the set of filters for photomicrography prepared under the name of Wratten M filters. The choice of the filter is decided by visual trial under the microscope, the filters chosen being those which most nearly absorb one color and transmit the other. Thus, photographing a section stained with Delafield's hæmatoxylin and precipitated eosin, the A filter (red) shows no trace of the eosin and gives a good, strong negative of the hæmatoxylin. The B and C filters are used together for the other negative, giving a blue-green color and recording the eosin and hæmatoxylin both fully, and from these two negatives positives are made and stained with a blue and a red dye.

NOTES FROM RESEARCH DIVISION, ELECTRICAL ENGINEERING DEPARTMENT, MASSACHUSETTS INSTITUTE OF TECHNOLOGY.*

EXPERIMENTS TOWARDS DETERMINING THE MAXIMUM EXTERNAL POWER OF ATHLETES.

It is sadly remarkable that, in spite of all our world's records of various athletic events, we are almost wholly ignorant of the maximum external power which a strong man is able to exert; *i.e.*, the maximum rate at which he is able to do mechanical work. This is a matter of importance from humanistic, statistical, physiological, athletic, and engineering standpoints. Some experiments in this direction have recently been made by a group of students,[1] and particularly by Messrs. Norman B. Ames and Lucas E. Schoonmaker, who made a thesis study of the subject.

The experiments were made by observing the time in seconds required to run up to different heights on a flight of stairs. The work done externally by the subject being equal to his weight multiplied by the difference of level from start to goal, the average power developed during the run is this amount of work divided by the observed time.

It was found that, taken from a standing start, the power developed increased rapidly as the height of the goal increased, until about four metres was reached. Increasing the climb beyond that height increased the power, but less rapidly. When the height of the climb was set at nearly nine metres, the power of the best athlete over the course reached a maximum, and in trials at yet greater heights the power fell off, owing to fatigue.

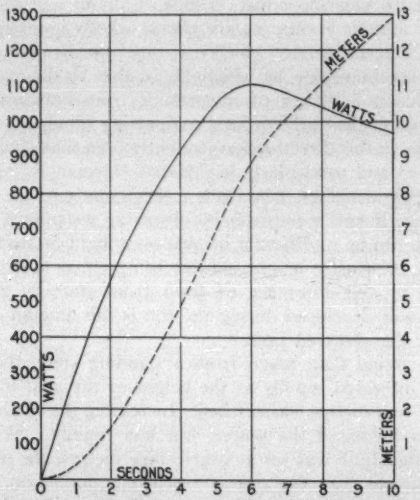
The best athlete weighed, clad, 76.5 kg. The work done in lifting his weight 8.83 metres was thus $8.83 \times 76.5 = 675$ kg.-m. The time of ascent being six seconds from standing start, his averaged power was 112.5 kg.-m. per second, or 1104 watts. An athlete can therefore develop an external power of 1.1 kilowatts, or about 1.5 horsepower.

* Communicated by the Director.

[1] For further particulars, see "The Horsepower Race," *Scientific American*, vol. 117, July 7, 1917, p. 12.

The accompanying curve sheet presents, by the heavy line of "watts," the power developed by this athlete in different intervals of time from successive trials; *e.g.*, 550 watts in a climb of two seconds' duration, 1000 watts in 4.7 seconds, and 970 watts in 10 seconds. The broken line presents the height attained in different intervals of time as found in the same series of successive trials; *e.g.*, 4.9 metres in four seconds, 8.83 metres in six seconds, 12.9 metres in 10 seconds. The watts curve varies

FIG. 1.



Average powers of a selected athlete over ascents of different durations up to 10 seconds. The broken line gives the corresponding elevations attained. Weight of athlete, 76.5 kg. (168 lbs.).

with different athletes, both in its maximum and in the time to reach a maximum, but it seems to have the same general shape in all of the cases thus far observed.

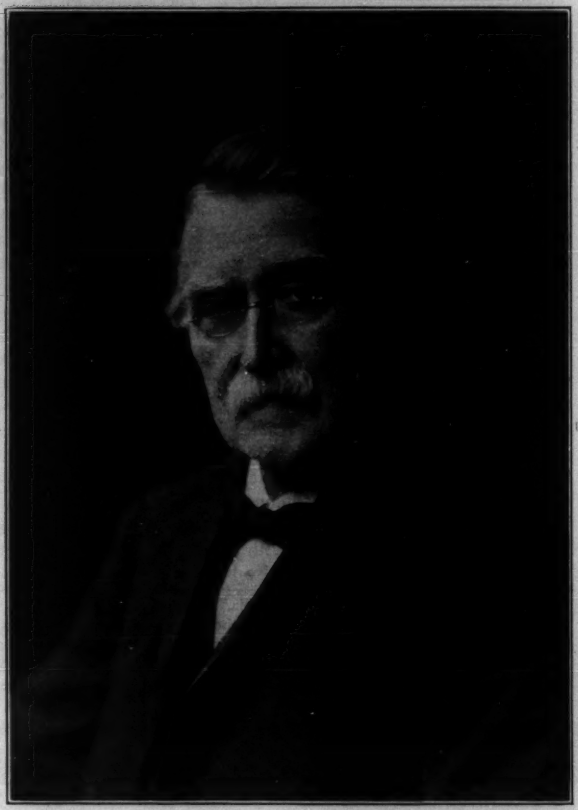
The results were obtained without any special training on the part of the athlete. They are therefore likely to be improved upon, and perhaps greatly improved upon, by selected athletes training for the event. It would be interesting to have such records accumulated.

The experiments were made on stairways in various places within Boston and Cambridge, Mass. The inclination of the stairway did not noticeably affect the results between the limits tried of 27°.4 and 37°.4.

It appears from world's records that in running contests over level ground the highest average speed over the course is attained in the 100-metre dash[2] (110 yards). This race has been run in 10.6 seconds with an average velocity of 9.43 metres per second. At shorter distances the speed is kept down by starting inertia, and at longer distances by fatigue. It is also known that the time of exhaustion or goal reaching, in all of the world's record events depending on speed (except cycling), varies approximately inversely as the ninth power of the speed over the course.[3] From the climbing records here reported, the best average speed is developed in about six seconds, with an average vertical velocity component of 1.47 metres per second; but these can only be regarded as preliminary indications. Many more observations will be needed to establish, to a satisfactory degree of precision, the maximum power which an athlete is capable of developing externally. The contest can readily be made competitive and spectacular. Perhaps only in active competition can the best maxima be secured. The leg muscles are manifestly the principal sources of the power developed in an uphill dash of this kind. It might therefore be possible to increase the output by providing balustrades along the stairway, with projections for enabling the athlete to urge himself upwards also by his arms.

[2] "The World Almanac and Encyclopedia," 1917, p. 391.

[3] "An Approximate Law of Fatigue in the Speeds of Racing Animals," *Proc. of the American Academy of Arts and Sciences*, vol. 42, No. 15, December, 1906, p. 275; also, "Deductions from the Records of Running in the Last Olympiad," *The Popular Science Monthly*, November, 1908, p. 385; also, "A Law of Record Times in Racing," *Nature*, March 14, 1907, p. 463.



FREDERICK GUTEKUNST
1831–1917

THE FRANKLIN INSTITUTE.

NECROLOGY.

FREDERICK GUTEKUNST.

1831-1917.

THE death of Frederick Gutekunst, on the 27th of April last, in the 86th year of his age, severed perhaps the last remaining link between the earliest years and the present of the photographic art. He was the Nestor of American photographers, a leader in the earliest varied applications of his art, and one who through a period of more than a generation stood as the most widely acknowledged master of photographic portraiture in America. In that field he held to the day of his death a place of marked distinction, and long ago had gained, through the sterling quality of his productions, a reputation which made his name to signify in reality, as well as literally, "good art."

Frederick Gutekunst was born September 25, 1831, in Germantown, the son of a German cabinetmaker who had settled in that suburb of Philadelphia. In his twelfth year he was diverted from his courses in the public schools to become a lawyer's apprentice in the office of the then Prothonotary of the Supreme Court, Joseph S. Cohen, to whom his father indentured him for two successive terms of three years each. During these six years, however, his natural bent to science rather than to learning became more and more pronounced. It had led him to spend more than half of his allowance of six cents per day for lunch on chemicals instead, and so, in his eighteenth year, he turned from the lawyer's office to become a drug clerk in Avery Tobey's apothecary shop at 1215 Market Street. There he put in the two next years and studied what had up to that time been discovered of photography and electricity. He then, as a youth of twenty-one, became a member of The Franklin Institute, utilizing its facilities to continue his studies in his favorite field of science. At the same time he turned from the drug business to that of photography, making daguerreotypes at first, and later applying the collodion process on glass for the production of ambrotypes. He also took up the then seemingly promising experiments for the turning of daguerreotypes into printing plates by electrolytic etching, but found, as did others at the time, the later collotype process to be more serviceable in the application of photography in the printing press. This method he early brought into practical use commercially, subsequently developing that branch into a separate establishment at Ninth Street and Girard Avenue. During the eighties this plant, in charge of a manager, proved unremunerative and was finally given up. Gutekunst would not leave his gallery; there he continued his lifework, gaining new distinctions to the number of 36 medals and diplomas and winning new laurels as the years went by.

There was nothing impressionistic, but much that was impressive, in Gutekunst's way with the camera. Whether he applied it to the production of such a picture as the panoramic view of the Centennial Exposition buildings in 1876, which gained for him not only royal decorations from the sovereigns of Austria and of Italy but also the appreciative recognition of the most accomplished experts of that day, or a picture of the Capitol at Washington at the same period, which remains to this day a standard presentation of its imposing subject, or whether he used it to produce a portrait, the result was a picture in which every feature was presented in the way that the normal eye would see the original under normal conditions and in a normal light.

There were not wanting at any time since the discovery of photography by Daguerre in 1839, and increasingly after the introduction of the collodion process in the fifties, photographers who sought to apply the camera for the production of "artistic," as distinguished from "realistic," effects, especially in portraiture. Paris early took the lead in this direction, and in time photographers in all the principal cities of Europe and America were vying with each other in the production of artistically posed and peculiarly lighted portraits, the so-called "Rembrandt effect," in which the lights of the picture were made subordinate to the shades, coming greatly into vogue, with less acceptable vagaries becoming here and there, for a time at least, the imprimatur of "quality."

In the midst of all these movements, however, Gutekunst kept on the even tenor of his way. He took the lead in his chosen field as the champion of "straight" portraiture. He insisted on making photographic portraits that were true to nature, with no attempt at anything but perfection in that respect. And that he certainly attained. He realized at once the limitations and the possibilities of the photograph as a register of physiognomy. The interpretation of physiognomy he left to the painter, whose translation of the original, as is the nature of translations, inevitably expressed somewhat of the translator's psychology, sometimes adding to, more often subtracting from, the original, and always more or less dissembling it. Gutekunst knew that a portrait could be idealized in the photograph no less than in the painting, but that the essential element of a portrait was its fidelity to nature. He realized that the artist's genius had not been supplanted by the camera nor his skill by the unconscious processes of chemistry, but that these agencies had given the artist a new potency in the attainment of a highly desirable end.

Gutekunst sought to produce a picture that would be a true presentment of his sitter's natural self, a photograph that would be a record of the sitter's normal mood, a portrait which would express, so far as a portrait can express, the sitter's innate characteristics, and he succeeded to a remarkable degree in the accomplishment of that purpose. So great was his success in that direction that he became famous as a "photographer of men," and likewise for the great number of his portraits of other famous men. Probably no other photographer has ever had so many of the leading men of his generation as sitters before his camera. During the Civil War so many of the officers of the army and navy and of the civil government flocked to his gallery that he became reputed at that period as the "official photographer,"

and from that time through all the succeeding years he maintained the high reputation which his earlier work had gained for him, and his place on Arch Street near Seventh continues to figure as a gallery of photographic portraits of leading men. There he worked in faithful devotion to his art through all the sixty years from November, 1856, when he started out on his definite course, steadfastly to within a few weeks of the close of his long and eminently useful life. His two daughters and a sister survive him.

Gutekunst combined an even-balanced mentality with an equally well-balanced temperament. Serious yet genial, dignified yet modest, his personality commanded the respect and gained the affection of all who came in contact with him. "F. Gutekunst," as he always signed himself, had come to be regarded as an institution in Philadelphia, and as such he will long be remembered.

LOUIS EDWARD LEVY.

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BOOK NOTICES.

EXAMPLES IN BATTERY ENGINEERING, by Prof. F. E. Austin, E. E., Hanover, N. H., published by the author, 1917. 90 pages, 39 illustrations, 4¾ × 7½ inches. Price, $1.25.

Almost any person of average intelligence can bungle through a technical problem, but commercial efficiency and discriminating judgment come only with that familiarity acquired by extensive drill work. Although there exists considerable literature on batteries, either in special monographs or in general treatises, there is probably no one work available from which commercial proficiency in the increasingly important subject of battery engineering may be attained.

The characteristic feature of this useful little volume is the large number of business-like examples of how batteries may be arranged for given purposes and output, and their possibilities and limitations. A number of

instructive curves are plotted and explained, showing the laws of variations of the different quantities. No attempt has been made to enter generally into the details of the component elements of batteries, though a short reference is made to the constructive elements of storage batteries. Brief but adequate space is devoted to principles and the use of the various constants employed in battery work. A perusal of this text should prove of decided value to any electrical student who wishes to acquire dexterity in dealing with battery problems.

LUCIEN E. PICOLET.

THE LIFE OF ROBERT HARE, AN AMERICAN CHEMIST, by Edgar Fahs Smith, Provost of the University of Pennsylvania. Philadelphia, J. B. Lippincott Company, 1917. 508 pages, illustrations, plates, portraits, 8vo. Price, $5.

During the first half of the nineteenth century the name of Robert Hare was one to conjure with in American scientific circles. His brilliant achievements as a chemical investigator and his original contributions to chemical philosophy were highly esteemed and much admired, yet, nevertheless, it may be doubted whether his contemporaries (with the exception of a few of his intimates) had any idea of the real value of his unique achievements as a pioneer in the fields of high-temperature research and electrochemistry. Here and there some quaint and ingenious apparatus devised by him may still be found among the lecture equipment of schools and colleges; but apart from such curiosities, there was little that remained to recall to the present generation the importance of Robert Hare's contributions to physical science until a few years ago, when Provost Smith, in his interesting book, "Chemistry in America," once more called attention to the fundamental character of this Philadelphia chemist's discoveries and inventions. In the present volume Doctor Smith now presents an intimate and fascinating account of the life and labors of Hare, and his narrative is largely based upon, and liberally interspersed with, the hitherto unpublished letters of his subject and other practically forgotten documents. A mere glance over the pages of this splendid volume suffices to impress us with the fact that in writing it the author performed a labor of love: it is a biography not unlike those which Grimaux gave us in his "Life of Lavoisier," and Jacob Volhard in his "Life of Liebig." It is a beautiful, sympathetic, and sincere tribute to a great man of science by one who has achieved great distinction in the same field of endeavor and in the same institution of learning. A careful perusal cannot fail to convince the reader that not a few of Hare's discoveries have laid the foundations of great technical achievements and industries in our own time. Among these may be mentioned the invention of the oxyhydrogen blowpipe, by which the modern platinum industry and the Drummond light of the ocean lighthouses were made possible; the *calorimotor* and the *deflagrator*, by the aid of which their inventor obtained such substances as metallic calcium, calcium carbide, phosphorus and graphite (*i.e.*, substances which have only recently become most important products of the electrochemical industries). Hare was also the original inventor of the mercury cathode, which now plays so important a rôle in the electrolytic manufacture of alkali and its by-products.

In typography, paper, and binding this volume leaves nothing to be desired. It is adorned with a fine portrait in color of Hare and with several double-tone illustrations. The reviewer knows of no biography of any American scientist which surpasses this either in interest or in attractiveness of appearance.

HARRY F. KELLER.

GRANDES VOÛTES par Paul Séjourné, Ingenieur en Chef des Ponts et Chaussées. Paris, Tardy-Pigelet et Fils. In six volumes, paper; 1732 pages, 1230 illustrations, tables, 10 x 13 inches. Price, 250 francs.

Probably the most monumental engineering treatise in any language is this work on "Great Arch Bridges," by the eminent French engineer, Monsieur Paul Séjourné. The limited space allotted to this review does not permit of more than a passing reference to a few of the salient features of the book.

M. Séjourné illustrates and discusses practically all of the important masonry and reinforced-concrete arch bridges of the world, in six volumes, which are a model for technical writers in all that relates to clearness, thoroughness, elegance of diction, and high standard of finish.

The illustrations are profuse and artistic, and are exceptionally well reproduced; and the general mechanical make-up of the work is of the highest order. The first four volumes consist essentially of tabulated matter and illustrations. These tabulations are worthy of the highest praise, containing, as they do, practically all the information that any reader could desire. The preparation of these tables alone must have necessitated many years of hard work and the taking of infinite pains. A conscientious study of the illustrations alone, even if the engineer does not read French, would in itself be a liberal education in the æsthetics of bridge design. Reference to this book by any American engineer contemplating the making of a design for a concrete arch bridge could not fail to be productive of very material help and benefit; and the æsthetics of bridge designing in this country would undoubtedly be greatly improved by a general familiarity with this work on the part of our structural engineers.

Many American engineers may consider the high price of this set of books to be prohibitive of personal acquisition, because they have been spoiled during recent years by the issue of so many fine American technical works at exceedingly low prices; but the librarians of the public libraries in our large cities should certainly purchase this treatise for reference-use by engineers; and our universities and technical schools should not fail to order it for their libraries. Whenever an important technical work like "Grandes Voûtes" is published, the benefit of the profession not only demands that its value should be realized and that it be utilized to the utmost, but its employment and recognition would in some measure be an acknowledgment and encouragement to the author for his laudable efforts for the good of mankind. Such recognition and encouragement are much needed by technical book writers, because the labor and expense of preparing the manuscript are very heavy, and the pecuniary reward is almost always *nil*.

J. A. L. WADDELL.

PUBLICATIONS RECEIVED.

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CURRENT TOPICS

Outwitting the Deadly Torpedo. ANON. (*Shipping Illustrated*, July 14, 1917, p. 27.)—It is always a thankless task to throw cold water upon the enthusiasm of neophytes who attempt to solve problems that baffle the mind of trained experts in ship construction, particularly when such efforts have as their object the devising of means to reduce ship losses by affording protection against submarine attack. Numerous have been the makeshifts proposed in order to afford merchant ships some measure of immunity against the torpedo, and, while scientists, naval constructors, and others have so far produced nothing which they would conscientiously recommend as a panacea, a host of amateurs have come forward with schemes which have gained in popularity through advertisement that which they intrinsically lack in merit. It is not only a sheer waste of time to experiment with mechanical puerilities, but a source of danger, because popular enthusiasm might be wrought up to such a pitch as to force the adoption of this or that device before any steps had been taken to demonstrate, by experiment, the fallacy of the premises upon which it had been evolved. These remarks are suggested by the exhibition, in the New York offices of the Salvage Association of London, of a torpedo defence for merchant ships, which consists of steel plates suspended about 12 feet apart from the ship's sides along the machinery space. The plates are about three-eighths inch thick, suitably braced and suspended on each side by outriggers. The protecting device is from 15 to 20 feet deep, the top edge being five feet below the surface of the water. These plates are in the form of panels so that they can be roused out or stowed home alongside the vessel in sections by the aid of hauling lines to the deck winches. The claim made by this defence is that a torpedo would explode on impact with the plate, and the intervening cushions of water between the panels and the side of the ship would absorb the explosive energy of the torpedo's warhead.

Probably the well-meaning people who have endorsed the steel plate defence scheme have no conception of what a high-speed projectile of the modern torpedo type, weighing 2700 pounds and charged with over 300 pounds of trinitrotoluene, is capable of doing, even if exploded at a very considerable distance from the side of the vessel. What the torpedo has proved itself incapable of doing at a distance of from 32 and, in some cases, 50 feet from the side of the vessel certainly cannot be done by a rigid device of the character described. In conclusion, it is well to inform the public that the Navy Department has warned inventors against wasting time and energy on the production of torpedo-defence schemes which con-

template fastening shields or plates, movable or otherwise, or masses of elastic material, on the outside of a vessel in the hope of either warding off the torpedo or causing it to expend its explosion harmlessly. Wire nets are used when the ship is at anchor, in perfectly smooth water, or moving very slowly, but they are practically of no avail in heavy seas, and, besides, are liable to be torn off and foul the screws. In many instances, also, they have been found easily penetrable by a high-powered torpedo. It is equally useless to arrange big electromagnets on a vessel for the purpose of making the torpedo swerve and so avoid the ship. They have an unfortunate tendency—supposing they work at all—to attract the torpedo to the ship instead of deflecting it. But, of all schemes, perhaps the most frivolous is for untrained minds to try to devise novel methods of ship construction for the purpose of enabling ships to keep afloat after being torpedoed amidships. The internal subdivision of ships has long occupied the attention of naval constructors, and it is folly for any one unversed in all the details of naval and mercantile ship design to come forward with suggestions that show *à priori* the inventor's lack of understanding of the elements of that branch of applied science known as naval construction.

Military Airplane Photography. A. BROCK, JR. (*Aviation*, vol. ii, No. 8, p. 347, May 15, 1917.)—As early as 1850 Captain de Laussedat, of the French Engineer Corps, suggested the use of photography for surveying, and as a direct result of his work attempts were made to take photographs from captive balloons even prior to the Civil War. Although at that date the art of photography had not sufficiently advanced, nevertheless photographic surveying soon became a success, even with the wet-plate process, and with the introduction of the dry-plate the method was adopted by a number of governments. When military airplanes came into use the value of photography for correct location and delineation of objects was well understood.

The primary object of airplane photography is to obtain a complete and perfect record of that part of the terrain seen from an airplane; another object is to obtain a record in large enough scale to permit the recognition of most of the points of importance; while a third is to permit the placing of the various objects, as seen on the photographs, in their true location on the map. The employment of dummy guns, tree branches, paint, etc., to create a false impression was practically coincident with the development of airplane photography. One result of such photographs has been to change entirely the manner of placing field-guns. Now, a well-marked gun-pit does not necessarily denote the presence of a gun, as there may be found three or four well-marked gun-pits to each gun in actual use.

In the European war it has been found advantageous to obtain records from day to day of the holes made by high explosive shells

which may be available for cover in carrying out attacks. This led to photographs large enough to permit of the closest possible identification in the negative or print. Until quite recently the average scale of military photographs was about 1/5000 actual size. Since this is the scale of a true horizontal photograph with a 12-inch lens at 5000 feet elevation, with the increased range of anti-aircraft guns, in some instances, lenses of extreme focal length were used. In practice, placing all enemy positions in their true location on the map has resulted in the location and destruction of field-guns a few hours after a photographic reconnaissance flight.

The Case-hardening of Iron by Boron. N. TSCHISCHEWSKY. (*The Mechanical Engineer,* vol. xxxix, No. 1007, p. 346, May 11, 1917; from *Proceedings of the Iron and Steel Institute,* May, 1917.)—On cooling iron-boron alloys, the boron is not wholly combined in the form of borides of iron, but a proportion of it is left in the form of a hard solution. This phenomenon suggests the possibility of case-hardening steel by boron similarly to the case-hardening of iron by carbon. Alloys of iron with boron are so remarkably hard that they can be scarcely attacked with an emery wheel. There is promise, therefore, in the technical application of case-hardening by boron of a feasible technical operation. The complete cementation that takes place in carbon steel is not the type of operation the author has in mind, but a surface cementation. It is more convenient to obtain a ferro-boric alloy by melting on account of the high price of boron, and also to secure its complete use without wastage. The use of boron is not perhaps suitable for armor plates, because of its comparative scarcity, but for some machine parts, and generally where much wear occurs, boron can be applied with success. No special heat treatment of articles hardened by boron is necessary, as is with articles case-hardened by carbon.

To ascertain the conditions of case-hardening by boron, cubes of soft iron were drilled in the centre to a depth of about half their length. These holes were filled with a fine amorphous boron or with powdered ferro-boron and the holes closed by iron plugs. In one experiment two samples were heated for two hours in an exhausted silicon tube at 950° C., one containing amorphous boron, the other powdered ferro-boron. Under the conditions of the experiment it was ascertained that cementation by powdered ferro-boron proceeds more easily and quickly than with amorphous boron. Microscopical examination shows that the hard white layer of the hardened part of the specimen consists of compact boric pearlite with a twin crystal structure. Case-hardening at a lower temperature yields an alloy of iron containing less boron. This alloy is not so hard and brittle as that described. In order to render the process suitable for industrial purposes it would be necessary to carry out a series of experiments on the conditions most suitable to the particular purpose in view.

Oxyacetylene Welded Versus Screwed Pipe Connections. ANON. (*Acetylene Journal*, vol. xviii, No. 11, p. 604, May, 1917.)—Supplementing tests made to determine the relative strength in tension and compression of oxyacetylene welded and screwed pipe connections, under the direction of Prof. F. H. Gibley, in the machine construction laboratory of the University of Kansas, reported in the March, 1916, issue of the *Acetylene Journal*, the same experimenters have completed tests on the strength of these connections when subjected to internal hydraulic pressure. The results of these tests bear out the conclusions given in the first series, namely: (*a*) The strength of the welded pipe connection is practically the same as that of unwelded pipe. By slightly building up the weld it can be made stronger than the rest of the pipe. (*b*) The strength of the welded pipe connection is much greater than that of malleable iron screwed fittings. (*c*) Although a careless or inexperienced operator may produce a leaky joint, nevertheless, if the pipe line is tested for leaks when installed, it should give no difficulty in service.

The pipe samples, which were cut from standard black steel pipe, were from the same stock and hence probably of uniform quality. Malleable iron couplings and ties were used for the screwed connections. The pieces for the butt welds were cut at an angle of about 60 degrees in a pipe-cutting machine to get the necessary "V" groove for welding. The "T" welds were made by cutting a hole in the run and butting the outlet against the run. The ends of all the specimens were sealed by welding in plugs or disks of boiler plate. Hydraulic pressure was supplied by means of a small pressure pump made for the work. Welded two- and three-inch specimens failed by splitting along the longitudinal seams of the pipe, the split stopping at the weld. A four-inch welded specimen bulged under the high pressure, but did not fail in either the weld or pipe seam. Two of the screwed connections failed by a tearing apart of the fitting at the thread. The bursting pressures of the screwed connections were far below those of the welded connections, and all failed in the fitting. Great difficulty was experienced in testing the specimens made up with screwed fittings because the leakage through sand holes made it almost impossible to reach the point of rupture. Only one case occurred in which there was failure at the weld, and that was merely a leak which did not develop until a pressure of 3850 pounds per square inch was applied.

Reducing Noise and Flash of Guns. N. FLAMEL. (*Scientific American Supplement*, vol. lxxxiii, No. 2158, p. 300, May 12, 1917. Translated from *La Nature*.)—To see unseen and to hear unheard are the two greatest factors of success in tactics and in strategy. Batteries no longer belch forth clouds of smoke to reveal their position. This we owe to Mr. Vieille, who was the first to achieve a really stable powder. Nowadays, smoke plays a part in war only to form a momentary mark or for signalling. Though it has been possible to sup-

press smoke by the use of powders that contain no mineral substances, or pure nitroglycerin, it has not been possible to suppress flame or flash. The Germans were the first to try to diminish flashes by adding to powders very small quantities of the salts of fixed alkalies or of the alkaline earth metals, such as the salts of calcium. They did not succeed. With cannon the flash always exists, though it may be diminished; but the moment the flame becomes less visible, smoke appears, and in the same measure that the flash diminishes in intensity the quantity of smoke is augmented; that is, the sum total of flame plus smoke remains constant. Nevertheless there has been some progress achieved, and the attenuation of the flame with a very light smoke is a satisfactory solution in the majority of cases. After nightfall the slightest flash reveals a gun, while smoke ceases to be visible and matters so little at night that black powders have often been used.

It is possible to arrive at a general solution of flash and noise by mechanical means, and it is essential to suppress noise as well as flash. These all resemble in general principle the familiar muffler used to silence the exhaust of the gas engine. In these devices the spent gases are diverted into a series of tortuous passages enclosed in a casing affixed to the muzzle in which they become cooled and lose much of their kinetic energy before escaping to the surrounding air. Numerous devices of this type have been designed and successfully used on rifles, but they do not appear to have been found applicable to the larger calibred ordnance. The Maxim silencer embodying this principle has been commercially produced in this country and exploited to a considerable extent for use with sporting rifles.

Automobile Storage Batteries. W. C. BROOKS. (*Proceedings of the American Electrochemical Society,* May 2–5, 1917.)—Following the invention of the pasted-plate type of lead storage battery in 1880 by Fauré in France and Brush in America, there has been no rival to this form of accumulator in portable service where high capacity per unit of weight is desired. It was therefore natural for this form of accumulator to develop into the present-day automobile storage battery. It has only one competitor, the nickel-iron cell, which, due to its high initial cost, internal resistance, and comparative bulkiness, is at present restricted to certain classes of industrial truck service. The nickel-iron cell is not used at all, to the writer's knowledge, in starting service in gasoline cars. No Planté or electrochemically formed pure lead plate batteries which are so familiar in central station and car lighting service are used on automobiles, on account of the low capacity per unit of weight and the difficulty of making a compact assembly, due to expansion of the positive plate in service. The automobile storage battery has therefore come to mean some compact, light form of pasted lead-plate element, generally in hard-rubber jars with thin wood separators. These cells are assembled into a battery with lead-alloy connectors and held in position by a hardwood case or tray.

There are three general divisions of service for automobile storage batteries: ignition, starting, and motive power. Ignition service is the first for which storage batteries were applied on gasoline cars. The discharge was extremely low, one-fourth to one ampère intermittently over a period of a month to a year. The batteries were charged at some service station whenever the user judged the battery to be exhausted. The storage battery proved fairly satisfactory for such service, but would have been displaced by the dry cell and magneto, had not the development of the high-efficiency tungsten lamps made possible electric lights. Then the storage battery became the only means to supply continuously the current for both lights and ignition. A few makers placed a generator on the engine to keep the battery charged.

The next development was the cranking motor. The cranking motor and the battery to run it solved the last major problem in popularizing the gasoline automobile. This service demands something entirely different from the battery. It not only has to furnish ignition for the engine, but current for several lights and energy up to one or two horsepower to start the engine. Thus the demand changed abruptly from a fraction of an ampère to several ampères continuously for lights and periodically 100 to 400 ampères for a few seconds, or even minutes, to crank the motor.

Electric vehicles were the first to use storage batteries, so it is in this service that the automobile battery has really developed, starting batteries being merely a modification of vehicle battery construction. This service demands for pleasure cars 60 to 80 volts and 25 to 50 ampères for four to six hours' continuous discharge. The discharge is intermittent, generally exhausting the battery about twice a week. Frequently, however, the battery is recharged before it is exhausted. The discharge rate is variable and batteries are often poorly cared for. Electric trucks require from 80 to 85 volts and 25 to 400 ampères, depending upon size of truck, grade of road, load, and speed. The heaviest current demand is on fire department ladder wagons, but the hardest service is on heavy trucks making long hauls which exhaust the battery daily.

Gravity Batteries of Low Local Action. ANON. (*Revue Scientifique*, vol. 55, No. 7, p. 208, March 24–31, April 7, 1917.)—The depolarization of primary batteries by means of oxygen in the air has often been attempted without much success. Oxygen, which is the depolarizer *par excellence*, available in the air in unlimited quantities and readily soluble in water, is apparently a most direct means to this end. The principal reason for the inefficacy of air as a depolarizer is that in all batteries the zinc electrode occupies the full height of the jar. It is easily understood that the small quantity of oxygen which dissolves at the surface attacks the zinc and, being thus combined, is evidently useless as a depolarizer. Another disadvantage of this local action of the oxygen on the zinc is that the elec-

trode is rapidly worn away at the surface of the liquid, with a consequent loss in efficiency. These effects are particularly emphasized in open-circuit batteries. An obvious remedy is to arrange the zinc element at the bottom of the jar with the lower part of the carbon brought as near to it as possible to reduce internal resistance.

To verify this hypothesis Mr. Ch. Fery constructed a cell (*Société Française de Physique*, January 16, 1917) consisting of a sheet of zinc 45 millimetres square, provided with an insulating winding of twine in cross form. Upon this rested a carbon cylinder 32 millimetres outside diameter. The battery contained 150 c.c. of an eight per cent. solution of ammonium chloride. This element was discharged through a resistance of 80 ohms for 42 days. The formation of zinc chloride should have yielded six ampère-hours, while the actual yield was nine ampère-hours, showing that the action of oxygen from the air not only depolarizes, but also contributes to the consumption of the zinc. At the beginning of the discharge the voltage was 0.87 volt; at the end, 0.52 volt. Crystals of ammonium-zinc oxychloride of zinc are formed at mid-point on the carbon, but at neither the top nor bottom. Depolarization takes place very rapidly as soon as action ceases on opening the circuit. This action is readily explained. The lower end of the carbon near the zinc is strongly polarized, while the upper part in contact with the air is not polarized. When the circuit is opened, currents are formed between the two extremities of the positive electrode, which operates like a gas battery on short circuit. A large element which discharged for seven months through a resistance of 100 ohms delivered 43.75 ampère-hours with a consumption of 1.24 grammes of zinc per ampère-hour; the theoretical consumption is 1.228 grammes.

The Modern Automobile Torpedo. E. F. CHANDLER. (*Scientific American*, vol. cxvi, No. 22, p. 548, June 2, 1917.)—It was the submarine that really brought out the full possibilities of torpedo attack, simply because of its ability to make its way within easy range without exposing itself to gunfire. The tactical possibilities of the submarine have led to the development of a torpedo especially adapted for submarine use—a short-range weapon carrying a charge of about 400 pounds of explosive, which is 30 or 35 greater than that which fills the warhead of the standard torpedo. This end has been attained by employing weight and space previously given up to the propelling medium not needed when operating at such short ranges as 300 or 600 yards at which the submarine strikes.

The earliest torpedo was merely a tapered wooden spar, capped with an explosive head and capable of being projected over short distances. It soon gave way to a shell containing a propelling system. But, in spite of its increased speed and superiority to the tapered wooden spar, this form of torpedo, with a range of about 500 yards, was far too erratic, even though brought to

a high state of mechanical perfection. It was the introduction of the gyroscope that gave us the modern automobile torpedo in providing a means of accurately maintaining its course and permitting a nearly doubled effective range.

As is well known, the body of the torpedo consists of a spindle-like shell of circular cross-section, tapering towards the after end and provided at the forward end with an explosive charge arranged to explode on impact, and a pair of driving propellers and steering gear at the after end. The intermediate space is occupied by a compressed-air tank, engine for driving the propellers, and auxiliaries. The early torpedo was driven by compressed air stored in the tank at 2000 pounds per square inch, driving a three-cylinder reciprocating engine at a pressure of 200 pounds per square inch, controlled by a reducing valve. In order to increase the range of the weapon, the air was heated by means of an alcohol flame at the exit orifice within the tank. The alcohol was ignited by a cartridge fired at the moment of discharge. This heating of the air had the additional advantage of eliminating freezing, which had always been a serious drawback when cold compressed air was used.

The modern torpedo, with a range of 5000 yards at 36 knots, is equipped with the same operating and controlling elements as the earlier type of weapon. The remarkable strides that have been made are due wholly to improvements in type and design of the component elements. For example, the air heater is now placed outside of the tank, and the engine is of the turbine type. In the earlier short-range torpedoes the gyroscope was spun by means of a spring which rotated the wheel at high speed by a sudden impulse. When the range was increased and it became necessary to store a greater amount of energy in the gyroscope during the short launching period of the torpedo—about a sixth of a second—it became apparent that a more powerful impulse was necessary. As a consequence the spring drive has been replaced by a small turbine driven by compressed air. By this device the efficiency of the gyroscope when released from connection with its driving mechanism retains its original plane of rotation, and any change in the course changes the relative position of the gyroscope's axis and adjacent structure. This angular movement is arranged to operate a compressed-air relay controlling the vertical rudders, and so any deviation from the course determined by the plane of rotation of the gyroscope is immediately corrected.

The torpedo is maintained in an even keel and at constant depth by the combined action of a fore-and-aft pendulum and a hydrostatic spring balance which control the compressed-air motor operating horizontal rudders. Any slight tilt changes the angular position of the pendulum, and any change in depth the hydrostatic pressure on the discharge, either of which immediately

operates the horizontal rudder control. By this means the torpedo travels in a somewhat sinuous, though, on the whole, substantially straight, course, at a mean distance below the surface closely approximating the set depth. With this hydroplane control of the depth and level position, the torpedo may have either positive or negative buoyancy; that is, it may be arranged to either sink or float when not in motion. When the warhead or explosive charge is attached, it is arranged to sink when not in motion, but with a blank head for practice work it is arranged to float for easy recovery. The explosive charge is detonated by means of a firing pin and primer. Normally the pin is locked in the safety position by a nut; but when the torpedo is fired, the water causes a little propeller at the entrance point of the warhead to rotate and unscrew the nut, leaving the firing pin free to be pushed back when the torpedo strikes the side of the ship, thereby detonating the charge.

Replacing Steam Hammer with Electric Drive. ANON. *Electrical World*, vol. 69, No. 25, p. 1209, June 23, 1917.)—The Cumberland County Power and Light Company of Portland, Me., has recently been successful in the conversion of steam-hammer equipment to electro-pneumatic service, a pioneer installation being made at the plant of the Marine Hardware and Equipment Company. At this plant a 1200-pound Bement-Niles steam hammer was in service, steam at about 90 pounds per square inch being required for many hours daily. To avoid condensation troubles, it was necessary to run the hammer practically continuously. As electric-motor drive had been adopted for other purposes throughout the plant, it was found possible to do away with the demand for continuous high-pressure steam by adapting the steam hammer to air operation and installing a motor-driven compressor to supply air for this purpose and other requirements.

The valve of the steam hammer was rebuilt for a fit of 0.0025 inch compared with a previous fit of 0.005 inch under steam service. The Hardware company purchased a 50-horsepower, 220-volt, three-phase, Westinghouse squirrel-cage induction motor designed for 900 revolutions per minute, and belted it to a 12-inch by 7-inch by 12-inch Sullivan compressor delivering air at 90 pounds to the storage tank supplying the compressor. A branch exhaust terminating at two ½-inch pipes led down the frame of the hammer to outlets directed upon the working anvil surface, so that all chips and scale are immediately blown away in operation. It was found that harder and quicker blows could be struck than under steam conditions. Control of the hammer is obtained by a foot valve and lever.

Droop of Guns. J. W. BUNKLEY. (*United States Naval Institute Proceedings*, vol. 43, No. 172, p. 46, June, 1917.)—Droop may be defined as the bending of a gun due to the elasticity of the metal and to the imperfections in the manufacture of the gun. It may be expressed also as the angle that the final tangent of the curved bore makes with the axis of the gun at the breech. The subject of droop in guns has only lately received considerable attention, because it is only in recent designs that the length has been great enough to produce any appreciable bending. In guns of 12-inch calibre and larger the length of the bore forward of the trunnions has become so great that the bending can be detected by the unaided eye. In some cases the droop has been found to be more than one-half an inch. The deflection of the actual gun will never be less than this computed amount, but will be greater, according to the conditions of assemblage. The causes of droop of guns may be divided into three general heads, namely: Elasticity of metal; design of gun; imperfection in the manufacture of the gun.

A formula has been developed by Ordnance Engineer Jeansen for computing the deflection of heavy guns. This formula gives the deflection of droop of a gun caused by its own weight, considering the gun as a beam, irrespective of the system of assembling or locking the various pieces of the gun together. The depression of a gun is the theoretical bending of the elastic gun under ideal conditions. The flexure of a long gun, due to the unsupported weights in front of the cradle, is modified to a considerable extent by a general difference of temperature. The manufacturer of guns also plays an important part in the amount of droop.

[Considered as a solid elastic beam, the problem of finding the deflection of a gun does not differ from that of determining the deflection of a beam of variable cross-section occurring in structural design. A method possessing the merit of avoiding the need of such a formidable expression as derived by the author is given in *Engineering News*, vol. ii, page 340, 1907. It entails considerable labor in computation, but it does not require reference to special notes or formulas that cannot be easily remembered. This method is also described in the latest edition of Johnston, Bryan and Turneaure's "Modern Framed Structures" and elsewhere.—ED.]

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